CANADA–SASKATCHEWAN
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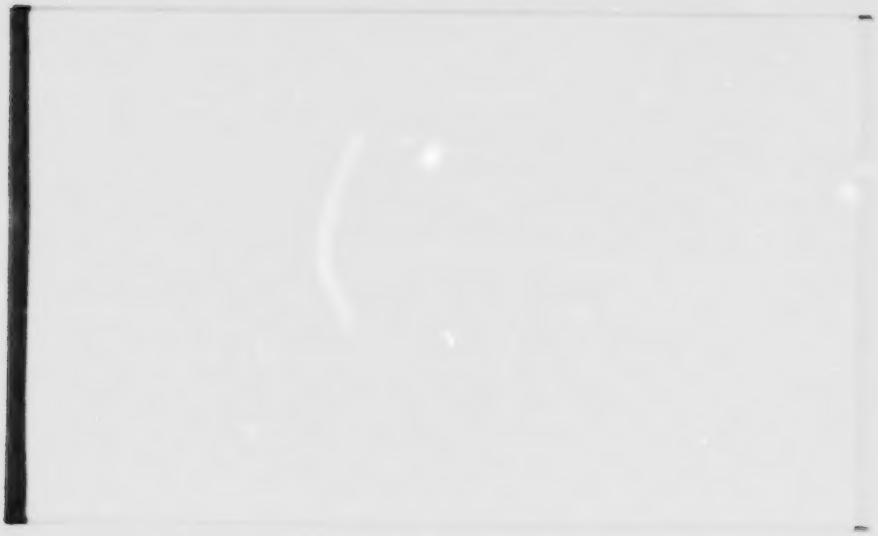

Canada

Saskatchewan

CONTRACT REPORT NUMBER 79220-01-SQ

CONTRACTOR: Potash Corporation of Saskatchewan

REQUISITION NUMBER 23440-7-9220

RESEARCH ON POTENTIAL COVER MATERIALS FOR POTASH TAILINGS

By: The University of Saskatchewan

For: Potash Corporation of Saskatchewan
and
CANMET

Contract # 01SQ.23440-7-9220

This study was co-funded by CANMET and Potash Corporation of Saskatchewan.

DSS Contract #: 01SQ.23440-7-9220
Science Contracting Officer: D. Frazer
CANMET Scientific Authority: D.G. Feasby
CANMET Project No: 30.21.02
Potash Corporation Project Leader: K. Reid

95 pp

March 1988

MICROMEL

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EXECUTIVE SUMMARY

The primary objective of this study was to investigate potential cover materials for use in sealing potash tailings. This report describes the work carried out and the progress made during the first phase of this study.

The generation of brine is one of the most serious problems facing the potash industry. Precipitation falling on potash tailings dissolves the tailings producing brine. The rate of brine generation is increasing, and environmental concerns are growing. For this reason, the industry is interested in pursuing methods of preventing brine generation by sealing the surface of potash tailings.

The cost of potential cover materials is high. One method of minimizing this cost is to use materials readily available at the mines. The insoluble fraction (slimes) of the waste potash tailings represents a possible material.

This study involved a laboratory testing program to evaluate the suitability of using these slimes as the primary constituent in a liner material or admixture. Various percentages of common "liner" material were mixed with slimes in the form of a slurry. These materials included till, lime, Kaolinite, flyash, and cement. The slurried materials were placed in thin lifts of simulate hydraulic field placement. This technique has been used with considerable success in the uranium and gold mining industries. Although this success has not been conclusively demonstrated in northern climates, the fluid condition of the slimes lends itself favourably to a hydraulic form of placement. Each successive lift was dried with heat lamps, and its rate of evaporation measured. Lifts were placed until a sufficient height of sample had built up to enable testing. Tests were carried out to determine the permeability, strength, and flexibility of each sample.

Preliminary results of this program indicate that the admixtures containing various percentages of Portland cement out-performed the other admixtures. These samples had a relatively low permeability and high strength. Permeability is required for low flows; while, flexibility and strength are required to accommodate shifting and settling of the tailings beneath the

proposed cover. They also showed little desiccation during drying. Future work will attempt to improve the cement-based admixtures and to evaluate the long-term performance of these and other potential cover materials.

RÉSUMÉ

L'objectif principal de ce projet était d'étudier les matériaux pouvant possiblement servir à recouvrir les haldes de résidus des mines de potasse. Ce rapport décrit le travail et le progrès accomplis durant la phase initiale de cette étude.

La production de saumure est un des plus sérieux problèmes que doit faire face l'industrie de la potasse. Les précipitations atmosphériques tombant sur les haldes de résidus dissolvent les résidus salins et produisent de la saumure. Le taux de production de saumure augmente, et les soucis de protection de l'environment deviennent plus sérieux. L'industrie est intéressée de développer des modes d'étanchéité des haldes de résidus, afin de prévenir et d'empêcher cette production de saumure.

Le coût des matériaux pouvant servir de couverture est élevé. L'utilisation de matériel déjà disponible sur les propriétès minières serait une facon de minimiser ces coûts. Les minéraux insolubles (argiles) présent dans les résidus présentent un certain potentiel.

Cette étude comprend un programme d'essais en laboratoire pour évaluer la possibilité d'utiliser ces argiles comme ingrédient principal ou secondaire de la couche de revêtement. Plusieurs dosages de matériaux communément utilisés pour ce genre de revêtement, ont été mélangés avec ces argiles, et mis en pulpe. Les matériaux testés comprennent de la moraine, de la chaux, de la kaolinite, des cendres et du ciment. Cette pulpe était par la suite étendue en couches minces pour simuler un placement hydraulique. La viscosité même de la pulpe suggère l'utilisation de placement hydraulique, bien que le succès de cette technique n'a pas été démontré en climat nordique. Toute fois cette technique a été utilisé avec un succès notable par l'industrie productrice d'uranium et d'or. Chaque couche superposée était séchée avec des lampes solaires et le taux l'évaporation était mesuré. Plusieurs couches étaient ainsi placées et conditionnées jusqu'à ce que l'épaisseur soit suffisante pour faire certain essais. Ces essais était pour déterminer la perméabilité, la résistance et la flexibilité de chaque mélange.

Les résultats préliminaires de ce programme indiquent que les mélanges comprennant divers pourcentages de ciment Portland surpassent les autres mixtures. Ces échantillons ont une perméabilité relativement basse et un haute résistance. Une faible perméabilité est nécessaire pour minimiser l'écoulement tandis que la flexibilité et résistance sont nécessaire pour accommoder le déplacment et le tassement des résidus sous la couche d'étanchéité. Une faible dessiccation a été observée durant le séchage. Les travaux futurs tenteront d'améliorer les mélanges à base de ciment et d'évaluer les performances à long terme de ces, ou de d'autre matériaux possibles.

1.0 INTRODUCTION

The prevention and control of brine generation is a major concern in the potash industry. Brine is generated by precipitation falling on highly soluble potash tailings. The current industry practice is to contain this brine in impoundments surrounded by dykes. However, as the volume of these tailings increases, it is becoming increasingly difficult to prevent the release of brine into the environment. One of the most promising approaches is to seal the surface of the potash tailing in order to prevent the generation of brine in the first instance.

This report describes the first phase of a two year study to investigate possible cover materials which might be used to seal potash tailings. The primary focus of this phase has been to examine the possible application of the insoluble fraction of the potash tailings as a component of the seal.

The insolubles were mixed with a variety of common liner materials such as cement, flyash, glacial till, kaolinite, etc. in an attempt to establish a prospective liner material. Tests were carried out on slurried samples to determine their engineering properties. The samples were hydraulically placed in a series of lifts and subjected to surface drying to simulate field conditions. The water contents of these samples were measured during the drying process. Test specimens were then taken from these samples for laboratory permeability, consolidation, unconfined compression, vane shear, and Tempe cell testing and visual evaluation.

This phase also involved the construction of a stainless steel triaxial permeameter. This permeameter will be used in a program to study the long-term impact of chemical and physical processes on the permeability of potential liner materials.

The results of this study indicate that the cement based admixtures present the most hope for the development of a suitable cover material. Thus, the program will focus in this direction as the testing program is intensified.

2.0 BACKGROUND

The construction of earth liners is one of the most economical means of constructing an impermeable barrier. However, the use of earth will not guarantee the success of a liner. These liners must be designed and constructed according to accepted fundamental principles of soil mechanics. They must also be designed to take into consideration the intended use.

The are four basic performance requirements which must be met in the construction of any liner. The degree to which these requirements must be achieved is a function of the particular application. However, they are all more or less important to some degree. These requirements are:

1) Degree of impermeability
2) Strength
3) Flexibility
4) Integrity

While it is relatively easy to design a liner system that will have the desired level of requirements initially, it is considerably more difficult to design for these requirements in the long term. Thus, the proposed liner material should be tested to determine its long-term performance. This can best be accomplished with very precise laboratory measurements of both permeability and volume change over relatively short time intervals (two to three months).

There are a number of factors which alter the structure of a soil-based liner. These factors can be grouped into physical and chemical processes. Physical processes include such factors as consolidation, wetting and drying, freezing and thawing, and erosion and dispersivity. The chemical factors include dissolution, osmotic consolidation, mineralogical transformation, sorption and precipitation. The second year (second phase) of this research will investigate how these factors will influence the performance of potential liner cover materials.

3.0 LITERATURE REVIEW

This review examines the work carried out to date on the solid component of potash ore.

In Saskatchewan, potash occurs in beds within the Prairie Evaporite Formation (Holter, 1969). Potash ore is a combination of solubles and insolubles. The soluble fraction makes up approximately 90 to 95% of the total solution, and is composed of halite (NaCl) and sylvite (KCl). The KCl fraction of the solubles is of considerable commercial value. The insoluble fraction is composed of anhydrite, dolomite, quartz and a lesser fraction of clay materials. Table 3.1 presents a mineralogical analysis of the insoluble fraction from various PCS mine sites.

Selected physical engineering tests were performed on the insolubles from the PCS Allan, Cory, Lanigan, and Rocanville mines by BBT Geotechnical Consulting Ltd. in 1982. Table 3.2 presents the results of these test for the insolubles after rinsing with fresh water (washed insolubles). The average specific gravity, liquid limit, dry density, and moisture content of the washed insolubles was 2.78, 20, 1647 g/cm^3, and 20.3 percent respectively. Problems were encountered testing the unwashed insolubles. These problems were primarily due to the interactions of the salt in insoluble with the admixtures.

Wong (1985) determined a fluid retention curve of the insoluble fraction from the PCS Lanigan division mine. The results of this analysis are shown in Figure 3.1. It illustrates the high level of suction required to dry this salt-rich material. The cause of this phenomenon is the low matrix suction values which occur at the air-soil interface. According to Hillel (1980), fluid retention under low suction (0 to 100 kPa) is a function of the soil structure, which is dependent upon the pore size and the capillary effect. In the higher range, the amount of fluid retained is due to absorption which is dependent on texture and specific surface of the soil material. Figure 3.1 shows that the insolubles retain a large amount of fluid content at any particular suction and exhibits a very gradual slope. Thus, at any particular suction value the insolubles exhibit a very small loss in moisture. This factor explains why insolubles mixed with brine do not dry out and desiccate.

Table 3.1

Summary of Mineralogical Analysis of Insoluble Fraction from PCS Mine Sites

(Taken from Environmental Affairs, PCS, 1984)

Notes: Analyses by the Saskatchewan Research Council

All samples obtained June to September, 1982.

Mineralogical Content In %	Allen Div		Cory Div		Lanigan Div		Rocanville Div	
	Average	Range	Average	Range	Average	Range	Average	Range
Quartz	17	14-20	19	15-21	23	18-26	22	18-27
Kspar/Microcline	9	2-14	1	0-2	6	5-8	5	0-10
Plagioclase	0	—	6	3-8	0	—	2	0-5
Calcite	2	2-4	2	2-3	2	1-2	3	1-4
Dolomite	15	13-20	17	12-20	12	12-13	34	31-38
Siderite	0	—	0	—	0	—	0	—
Pyrite	0	-	0	—	0	—	0	—
Gypsum	1	0-1	0	—	1	0-4	1	0-1
Anhydrite	6	2-9	2	0-8	4	3-6	13	8-17
Illite	26	16-35	27	21-38	29	23-33	13	10-18
Chlorite	6	3-8	7	2-9	5	5-6	2	1-3
Septechlorite	18	13-28	19	16-22	18	12-21	8	4-12
Montmorillonite	0	—	0	—	0	—	0	—
Mixed Layer Clays	0	—	0	—	0	—	1	0-1
Total % Clays	50		53		52		23	
No. of samples	9		9		7		8	

Notes: -Analyses by the Saskatchewan Research Council

-All samples obtained June to September, 1982

Table 3.2

Physical Test Results of Insolubles (Taken from BBT, 1982)

Sample		Washed							
Test Determination		LL	PL	PI	SL	Gs	MDD	OMC (%)	Total Clay Content (%)
Mining Location	Date								
Allan	June 11/82	42	24	18	17.2	2.74	1660	19.8	54
Allan	June 21/82	45	24	21	20.9	2.84	1637	22.4	48
Allan	June 25/82	43	23	20	19.7	2.75	1645	18.6	48
Cory	Sept. 27/82	30	21	09	23.0	2.87	1748	18.0	37
Cory	Sept. 28/82	41	22	19	25.3	2.82	1693	20.5	64
Cory	Sept. 30/82	40	20	20	21.0	2.78	1679	21.4	53
Lanigan	Oct. 07/82	37	21	16	20.8	2.75	1678	18.6	56
Lanigan	Oct. 13/82	40	22	18	20.2	2.82	1627	20.6	52
Lanigan	Oct. 20/82	32	19	13	28.6	2.93	1706	17.7	48
Rocanville	Oct. 05/82	30	18	12	24.2	2.77	1832	14.0	25
Rocanville	Oct. 07/82	29	18	11	18.3	2.76	1783	16.8	22
Rocanville	Oct. 19/82	28	18	10	23.1	2.76	1781	16.5	15

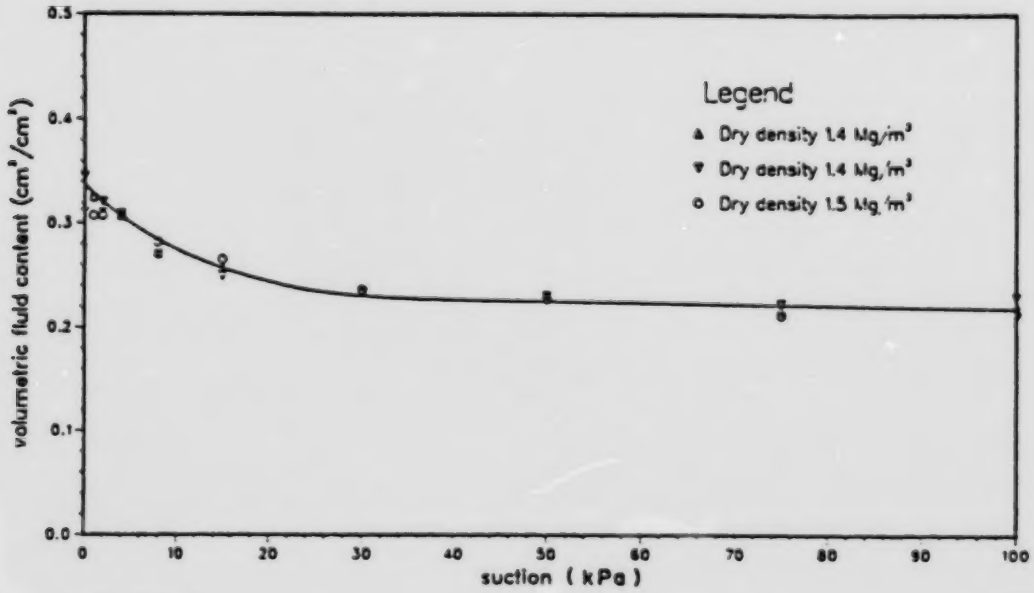

Figure 3.1

Laboratory Fluid Retention Curve for Insolubles from PCS Lanigan Mine (after Wong, 1985)

4.0 SAMPLING PROGRAM

4.1 SAMPLE SOURCES

The Potash Corporation of Saskatchewan (PCS) Allan Division was selected as the source of waste insolubles for this project. The PCS Allan Division mine is located 5 km north of the town of Allan, Saskatchewan.

4.2 COLLECTING AND HANDLING OF SAMPLES

Samples of slimes containing brine and insolubles were obtained in January and February, 1988, by engineers from PCS Allan Division and research engineers from the University of Saskatchewan. The insolubles in this brine consisted of salt crystals and other insoluble materials.

Samples of slimes were collected on January 27 and February 25, 1988, from the slimes thickener discharge. All samples were stored in 22.0 litre plastic pails. All pails were sealed with plastic lids. The insolubles were separated from the slimes by decanting brine off the slimes after a period of settling. Samples were then transported in these pails to the University of Saskatchewan and stored at controlled temperatures (70-72°C) until testing. This type of storage prevented any significant cementation of the salt crystals.

5.0 LABORATORY TESTING PROGRAM

5.1 INTRODUCTION

This chapter outlines the testing program and procedures used to determine permeability, compressive strength, shear strength, fluid retention curves and evaporation characteristics of various admixed materials combined with potash insolubles. These materials comprised of Type 10 cement, Type 50 cement, Battleford till, flyash, and kaolinite.

5.2 TEST MATERIALS

5.2.1 POTASH INSOLUBLES

The potash insolubles were obtained from the slimes thickener discharge pipe at PCS Allan Division Mine. Quantitative analyses of the insoluble mineral constituents were conducted by the Saskatchewan Research Council (SRC), using x-ray defraction techniques. These analyses were performed on dried insolubles containing salt crystals and brine. Results of this mineralogical analysis is presented in Table 5.1. The analysis shows illite, septechlorite, quartz, and dolomite are the major components. The Allan samples contained approximately 50% clay contents. This percentage is similar to the PCS Cory and Lanigan Divisions mines and is approximately double the Rocanville Division mine levels.

A hydrometer analysis was carried out at the University of Saskatchewan to determine the gradation of the potash insolubles. The slimes were washed free of brine (electrical conductivity of 8000 umhos) before the analysis was performed. The dispersing agent used was hexametaphosphate. Figure 5.1 shows the gradation curve of the potash insolubles (BBT, 1983). The grain size of the insolubles used in this study were 100 percent finer thant the No. 200 sieve (0.074 mm).

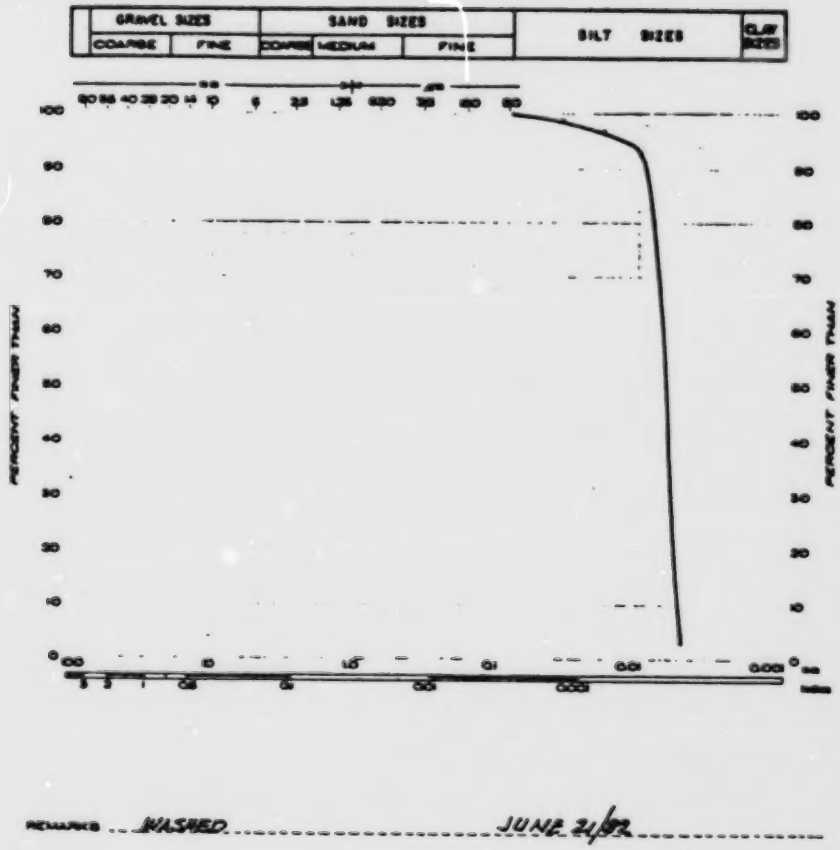

Figure 5.1
Hydrometer Analysis of Insolubles from PCS Allan Division Mine (BBT, 1983)

Table 5.1
Mineralogical Analysis of Insolubles from PCS Allan Division Mine

MINERALOGICAL CONTENT IN %	ALLAN DIVISION
QUARTZ	10.8
SYLVITE	19.9
DOLOMITE	27.4
HALITE	21.3
ANHYDRITE	12.5
KAOLINITE	6.2
ILLITE	1.9

5.2.2 BRINE

Brine was obtained from the slimes thickener discharge pipe at the PCS Allan Division Mine. A chemical analysis of the brine was performed by the PCS Allan Division laboratory. The results of this analysis is presented in Table 5.2. It shows that NaCl and KCl form the major constituent of brine with smaller amounts of calcium, magnesium and sulphate.

Table 5.2
Process Brine Analysis performed at 25.7°C.

CONSTITUENT	PERCENTAGE
KCl	10.8
NaCl	18.7
Ca^{2+}	0.17
Mg^{2+}	0.13
SO_4^{-2}	0.17
H_2O	70.03

The solids content of the slimes was analysed at the University of Saskatchewan. An average solid content of 32.0 percent by weight at 26°C was obtained (i.e. brine constituted 68 percent of the slimes).

5.2.3 CEMENT

Two types of cement were chosen as an admixture to the insolubles. These were Type 10 and Type 50 cement. Type 50 is a sulphate resistant cement containing less tricalcium silicate ($3CaOSiO_2$) and more diacalcium silicate ($2CaOSiO_2$) than Type 10. The chemical makeup of these two cements is shown in Table 5.3

Table 5.3
Typical Values of Compound Composition of Portland Cements of Different Types (Neville, 1973)

Cement	Value	Compound composition, per cent								Number of Samples
		C_3S*	C_2S*	C_3A*	C_4AF*	$CaSO_4$	Free CaO	MgO	Ignition Loss	
Type 10	Max.	67	31	14	12	3.4	1.5	3.8	2.3	
	Min.	42	8	5	6	2.6	0.0	0.7	0.6	
	Mean	49	25	12	8	2.9	0.8	2.4	1.2	21
Type 50	Max.	54	49	49	15	3.9	0.6	2.3	1.2	
	Min.	35	24	24	6	2.4	0.1	0.7	0.8	
	Mean	43	36	36	12	2.7	0.4	1.6	1.0	22

* Abbreviation	Name of Compound	Oxide composition
C_3S	Tricalcium silicate	$3CaO.SiO_2$
C_2S	Dicalcium silicate	$2CaO.SiO_2$
C_3A	Tricalcium aluminate	$3CaO.Al_2O_3$
C_4AF	Tetracalcium aluminoferrite	$4CaO.Al_2O_3Fe_2O_3$

5.2.4 BATTLEFORD TILL

The till used was as an admixture was oxidized and contained approximately 45% sand, 35% silt, and 20% clay. This till was hard and nuggety and had to be ground down into a powder to facilitate mixing with insoluble to create a slurry. A mechanical grinding wheel was used to grind this material to a grain size finer than a Number 40 sieve.

5.2.5 LIME

Lime used in this study was a commercial Calcitie Quick Lime, (CaO), having the composition and gradation indicated in Table 5.4. The lime was kept in sealed containers to prevent carbonation of the lime with the carbon dioxide in the air.

Table 5.4
Lime Chemical Analysis

Ingredient	Supplier (% by weight)	SRC (% by weight)
CaO	94.10	94.90
MgO	0.08	1.45
CaO + MgO	94.18	96.35
SiO_2	1.70	1.90
R_2O_3	1.75	1.10
Impurities	3.45	3.00
Loss of Ignition	1.60	0.40

Supplier - Steel Brothers of Canada
SRC - Saskatchewan Research Council testing results

5.2.6 FLY ASH (SUNDANCE)

Sundance™ fly ash from Alberta was used for this study.

5.2.7 KAOLINITE

The Kaolinite used in this study was of a powder commercial grade. Kaolinite is a relatively inactive clay mineral composed of a single tetrahedral sheet and a single alumina octahedral sheet.

5.3 TERMS AND DEFINITIONS

The high salt content of the slimes made them difficult to classify with standard laboratory soil mechanics tests. Modifications or unique definitions of material properties used in this study are discussed in this section.

5.3.1 WATER CONTENT

Water content is expressed as the percentage of water by dry mass of the soil sample, i.e.

$$\text{Water Content (W/C)} \% = (M_{Water} / M_{Soil}) \times 100$$

The masses are determined by oven drying the soil sample.

Where the pore fluid is composed of saturated brine (water saturated with dissolved salt), oven drying the sample results in re-crystalization of the dissolved salt. The dissolved salt content of the pore fluid should be taken into account. This was handled as follows:

$$\text{Water Content}_{adj} \text{ (W/C}_{adj}) \% = M_{Water} / (M_{Soil} + M_{Crystals})$$

Thus, unless otherwise noted, the term water content refers to the adjusted value.

5.3.2 DRY DENSITY

Dry density is expressed as the weight of dry mass of the soil sample by one plus the water content i.e.

$$\gamma d = M_{Soil} / (1 + W/C)$$

Since the measurement of dry density includes the measuring of the water content, the dissolved salt content of the pore fluid must be taken into account. This is done as follows:

$$\gamma d_{adj} = (M_{Soil} + M_{Crystals}) / (1 + W/C_{adj})$$

5.3.3 SOLIDS CONTENT

The percentage of insoluble potash slime is defined as follows:

$$\text{Insoluble Solids Content} = W_{solids} / (W_{solids} + W_{crystals} + W_{water} + W_{dissolved\ salt})$$

5.4 COMPOSITION OF COVER MATERIALS

Various percentages of cement, flyash, Battleford till, lime, and kaolinite were mixed with potash insolubles. Table 5.5 shows the percent mixed with potash slime on a dry soil weight.

Table 5.5
Composition of Admixtures with Insolubles

MATERIAL	PERCENTAGE (%)			
	2.5	5.0	10.0	50.0
Type 10 Cement	*	*	*	
Type 50 Cement	*	*	*	
Lime	*	*	*	
Flyash	*	*	*	
Battleford Till		*	*	*
Kaolinite		*	*	*

Percentage mix of cement, flyash, and lime ranged from 2.5 to 10 percent. Mixtures of Battleford till and kaolinite were tested between 5 and 50 percent.

5.5 PREPARATION OF SAMPLE COVER MATERIALS

Potash insolubles collected from the PCS Allan Division Mine were used as the base material to form the cover. Excess brine was decanted off the pails containing slimes, and the solids content of the brine solution was determined. This was done so that corrections for the salt crystals in the potash insolubles could be made. Moisture contents of the insoluble samples were then determined and percent admixtures were based on total dry soil weight of the insoluble fraction.

Moisture contents of the potash slimes ranged from 55 to 70 percent. Percentage of solids in the brine solution was approximately 32.0 percent. The potash insolubles were mixed in a wet state and poured into glass containers in 10 mm layers as shown in Figure 5.2 to a height of approximately 100 mm. All samples were exposed to heat lamps for 16 hours each day. Figure 5.3 shows the laboratory set up with the heat lamps and glass containers. All samples were made in multiples of threes. An electric fan was also used to promote evaporation. Room temperatures ranged between 26.0° C and 32.0° C. The temperature range was due to the amount of natural sunlight present in the laboratory.

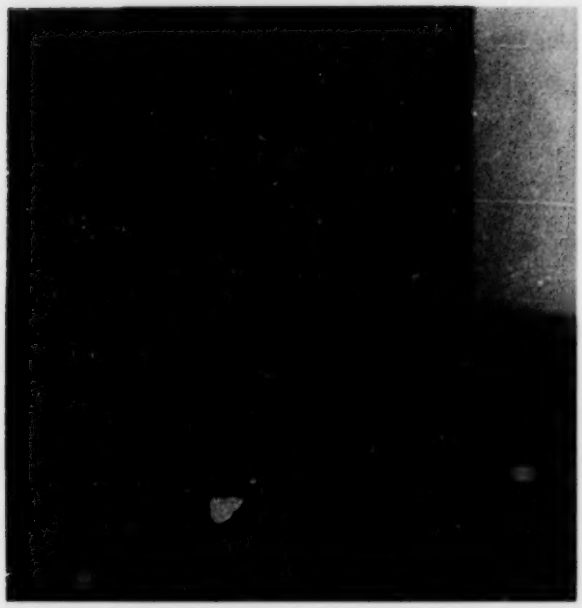

Figure 5.2
Insolubles Containing a 10% Battleford Till in Glass Jar

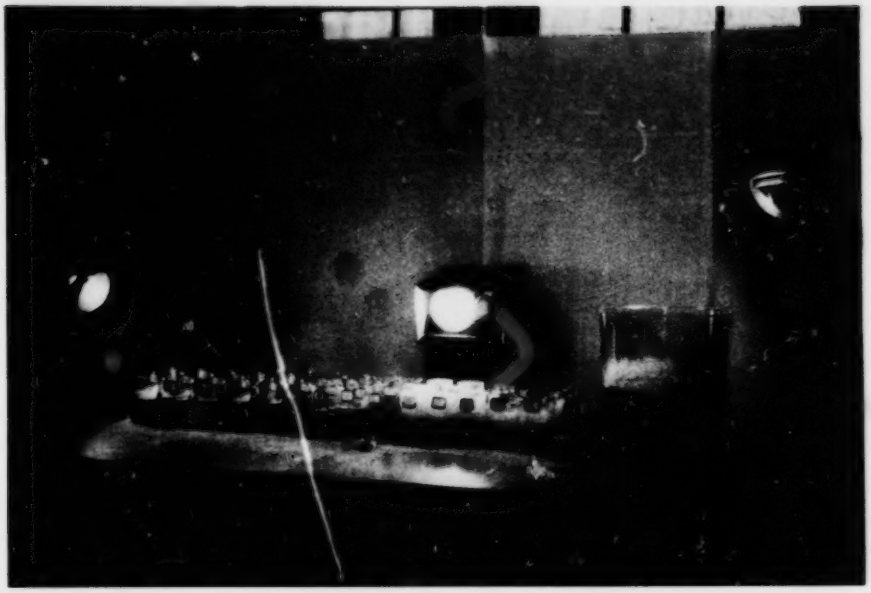

Figure 5.3
Laboratory Set Up of Potential Cover Materials

5.6 PERMEABILITY TEST

Permeability is the proportionality factor in Darcy's law as shown below and is defined as the discharge velocity through a unit area under a unit hydraulic gradient.

$$Q = Kia$$

where: Q = flow rate (dv/dt)
K = permeability (cm/sec)
A = Cross-sectional area of flow (cm^2)
i = Hydraulic gradient = dh/dx (dimensionless)

Permeability is a function of not only the porous medium but also the fluid properties.

A rigid-walled, clear-plexiglass cylinder was used as a permeameter cell for the one-dimensional content head permeability test. This apparatus is shown in Figure 5.4.

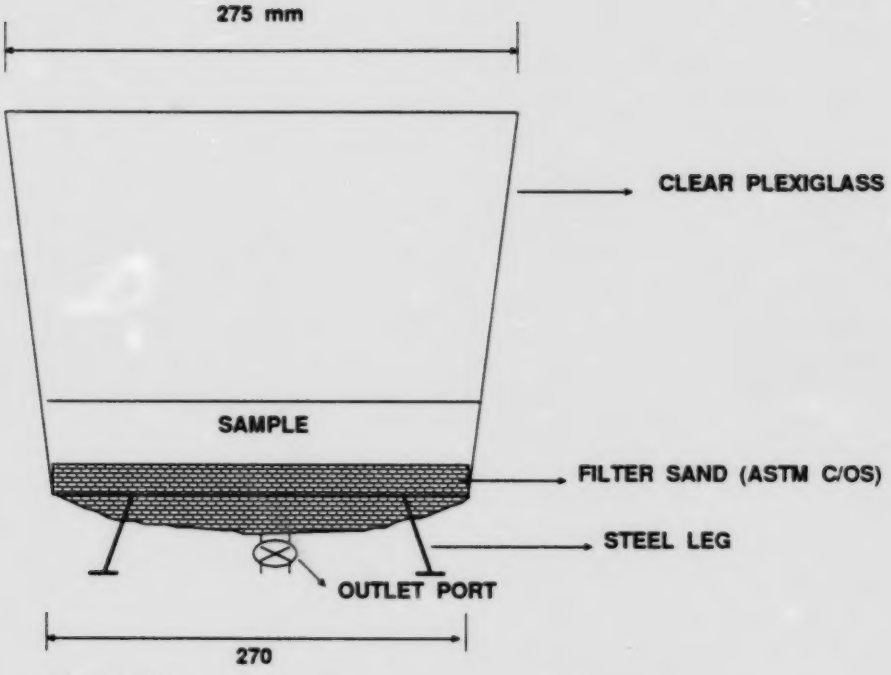

Figure 5.4
Constant Head Permeameter

5.6.1 SAMPLE PREPARATION

Samples were prepared in the same manner as described in Section 5.5 except that the material was placed in the rigid permeameter cell rather than in a glass jar.

5.6.2 TESTING PROCEDURE

The samples were allowed to dry for two days before being subjected to a 65 mm head of fresh water. Flow rate, Q, was determined by measuring the volume of permeament collected from the outlet port and recording the time. Electrical conductivity of the permeament was measured after each flow reading to determine the concentration of the brine solution.

5.7 CONSOLIDATION TEST

One-dimensional, constant-volume consolidation tests were carried out following ASTM D2435-80 on light frame loading devices with a mechanical advantage of 1 to 8 (Fig. 5.5). The results of these test are presented in Table 5.6. Brine was used as the solution in performing all test, except for the washed insolubles. Fresh water was used for these insolubles.

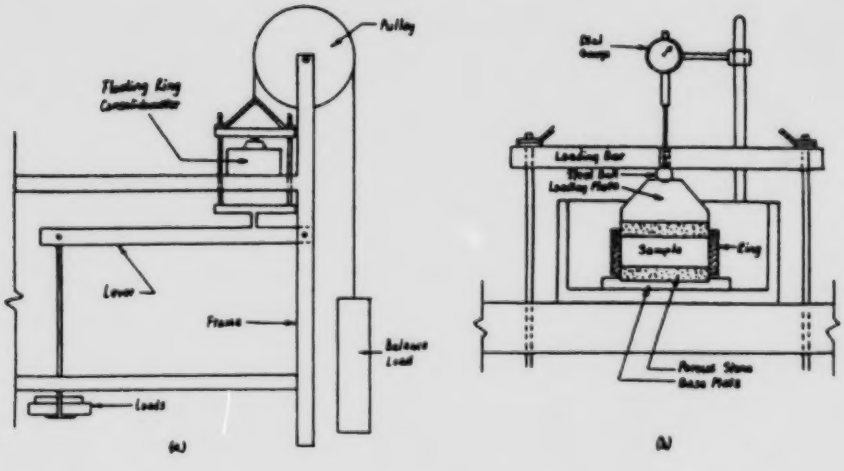

Figure 5.5
Consolidation Testing Device

Table 5.6
Consolidation Test Series

ADMIXTURES	LIQUID IN PREPARATION OF SAMPLE	LIQUID IN TESTING SAMPLE
Type 10 Cement 2.5% 5.0% 10.0%	Brine	Brine
Type 50 Cement 2.5% 5.0% 10.0%	Brine	Brine
Battleford Till 5.0% 10.0% 50.0%	Brine	Brine
Flyash 2.5% 5.0% 10.0%	Brine	Brine
Kaolinite 2.5% 5.0% 10.0%	Brine	Brine
Lime 2.5% 5.0% 10.0%	Brine	Brine
Insoluble - Natural	Brine	Brine
Insoluble - Washed	Brine	Water

5.7.1 SAMPLE PREPARATION

5.7.1.1 CEMENT ADMIXTURES

Type 10 and Type 50 cement samples were sufficiently stiff to be extruded from the 105 mm by 65 mm diameter glass jar. The samples were trimmed to the inside diameter of the consolidation ring (63 mm) and flush with the plane surface of the ring. The specimen height was made less than the ring height by partial extrusion and trimming.

5.7.1.2 KAOLINITE, FLYASH, BATTLEFORD TILL, AND POTASH INSOLUBLES

The Kaolinite, flyash and Battleford till admixtures were very soft and could not be extruded from the glass jars. Thus, these samples were prepared directly in the consolidation ring in a similar manner to that use with the glass jars. Two lifts were hydraulically placed within the consolidation ring. The specimen height was then made less than the ring height by partial extrusion and trimming.

5.7.2 TESTING PROCEDURE

The mass and dimensions of the specimen were determined in the consolidation ring. The samples were placed in a consolidometer with a saturated porous stone on each face. The consolidometer was placed in the light frame loading device and a dial guage was attached to the consolidometer. The softer samples such as kaolinite, flyash, Battleford till, and the natural potash insolubles were loaded with very light initial loads (i.e. less than 1 kPa). Specimens were then loaded to maximum of 1000 kPa.. Change in height of the specimen at time intervals of approximately 0.1, 0.25, 0.5, 1, 2, 4, 8, 15, and 30 minutes, 1, 2, 3, 8, etc., hours were measured from each of the incremental pressures applied.

In order to determine the rebound characteristics, the sample specimens were unloaded in reverse order with each successive load being only one-fourth of the preceeding load. Dial readings were taken as during loading. After completion of each test, the sample was weighed.

It was necessary to keep the concentration of the brine used in the consolidation apparatus constant during the test. This was accomplished by covering the brine in the consolidometer with a thin layer (3 mm) of motor oil. This technique was pioneered at the University of Saskatchewan for work on potash tailings and has been found to have no impact on the test results.

5.8 UNCONFINED COMPRESSION TEST

The unconfined compression test a test used to determine the shear strength of a cohesive soil. Shear strength is defined as the maximum resistance of a soil to shearing stress and is made up of two components. The first is friction, as in cohesionless soil. The second is cohesion, which is that component strength not due to friction. Shear strength is usually expressed by the Coulomb equation:

$$T = c + \tan \phi$$

where: c = cohesion
ϕ = angle of internal friction

Cohesion of a soil is not a constant soil property, but is a function of the load carried by the soil structure and the details of the test by which it is determined.

5.8.1 SAMPLE PREPARATION

A 130 mm by 47 mm diameter Shelby tube was used to obtain undisturbed samples from the prepared glass jars as outlined in Section 5.5. Flyash, kaolinite, and Battleford till samples were too soft to be sampled, thus no unconfined compression tests were performed on these admixtures.

5.8.2 TESTING PROCEDURE

Testing procedures were carried out in accordance with ASTM D2166. A sample specimen with a ratio of 2 to 1 is placed within the testing machine, as seen in Figure 5.6, with its vertical axis as near to the centre of the loading plates as possible. The loading plates were adjusted so that they just make contact with the specimen. The dial on the proving ring and on the vertical deflection guage were zeroed. A load was applied so that the specimen fails within 10 to 15 minutes. Stress readings were taken at 0.025, 0.05, 0.15, 0.2, 0.25, 0.3 etc. mm deflections until failure.

5.9 LABORATORY VANE SHEAR

The laboratory vane shear test is another test used to determine the shear strength of soil. The vane shear test consists of placing a four-bladed vane in the soil and rotating the vane until a cylindrical surface is sheared. Figure 5.7 depicts the laboratory vane shear apparatus. This test can be used on both soft and firm soils.

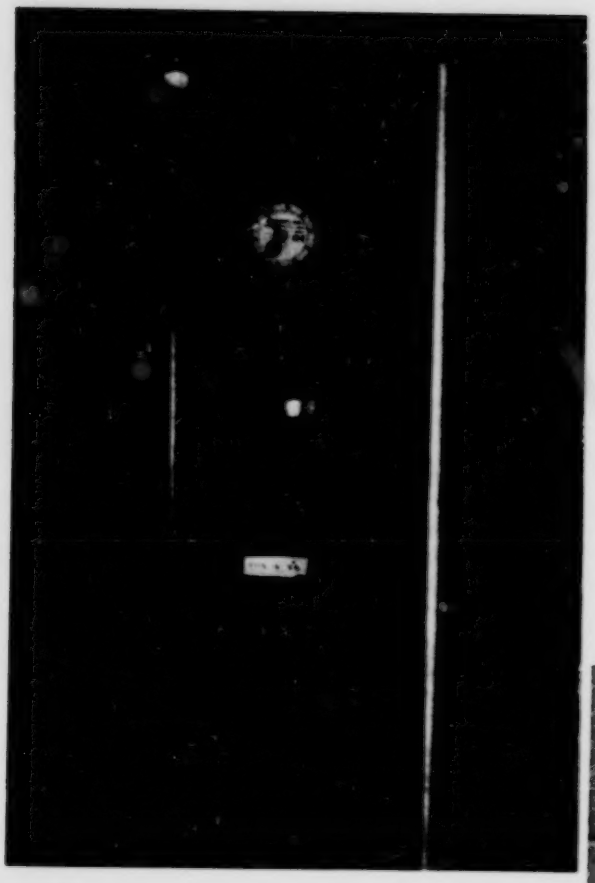

Figure 5.6
Unconfined Compression Apparatus

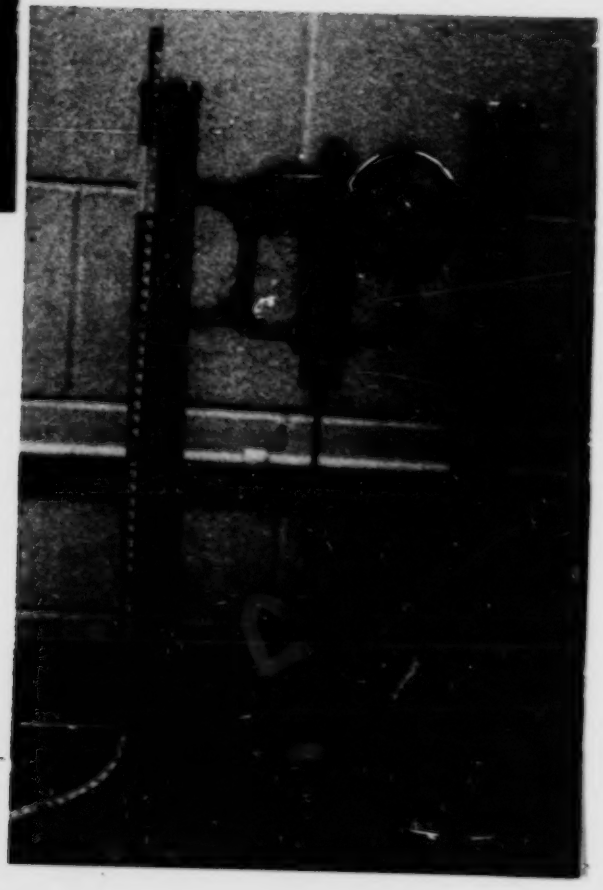

Figure 5.7
Laboratory Vane Shear

5.9.1 SAMPLE PREPARATION

Samples were prepared as outlined in Section 4.1 to a height of 100 mm.

5.9.2 TEST PROCEDURE

A specimen was placed within the testing apparatus, and the four-bladed vane was lowered so that it penetrated the surface of the sample. The vane was rotated until a cylindrical surface was sheared, at which time the shear strength was determined. The vane was cleaned and lowered an additional 15 to 20 mm, and the process repeated to the bottom of the sample. The admixtued samples were tested from 0 to 75 mm in depth.

5.10 FLUID RETENTION CURVE

Fluid retention curves are used to determine the volumetric fluid content (0) of a sample specimen against various pressures. These curves were determined using a commercial apparatus called a Tempe Pressure Cell as seen in Figure 5.8. The Tempe Pressure Cell is composed of a stainless steel ring, one bar air-entry ceramic disc, two "o" rings, and two 100 mm diameter plexiglass ends.

The Tempee pressure cell operates under the same physical principles as the porous-plate apparatus described in ASTM D2325-68 and ASTM D3152-72.

5.10.1 SAMPLE PREPARATION

No special technique was required to prepare the samples for the tempe cell test. Samples of potash insolubles were taken out from the storage pail and placed in the tempe cell.

5.10.2 TEST PROCEDURE

The porous plate was saturated with a brine solution obtained from the PCS Allan Division mine. A sample was placed within the 60 by 84.3 mm diameter stainless steel ring. The pressure cell was then sealed and increments of negative air pressure applied to the sample to dry it out. The sample drained, in response to this pressure, through the saturated porous air-entry ceramic disc. The pressure cell was weighed daily until equilibrium was established with respect to each incremental suction. Volumetric fluid content was then determined for each pressure increment (i.e. 0.02, 0.05, 0.10, 0.20, 0.25, 0.35, 0.50, 0.75 kPa) using the weight of the pressure cell corresponding to each equilibrium pressure and the over-dry weight of the sample.

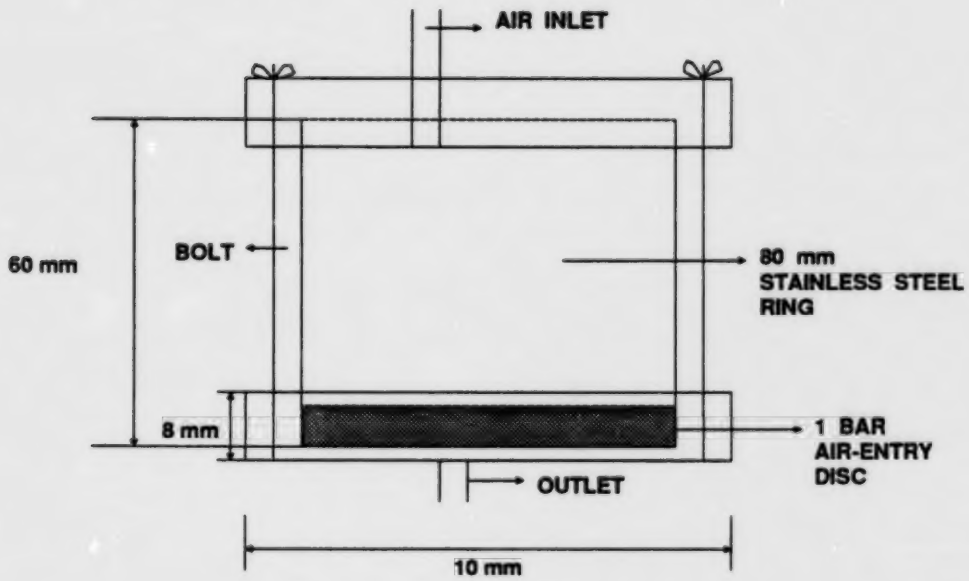

Figure 5.8
Tempe Cell

6.0 CONSTRUCTION OF EQUIPMENT

A triaxial permeameter was designed and constructed during the reported period at the University of Saskatchewan. A schematic diagram of this apparatus is shown in Figure 6.1. High-grade stainless steel tubing and fittings were used in the construction of the permeameter to minimize leakage and corrosion. This permeameter was designed to handle sample diameter of 100 and 200 mm diameter, and to be capable of accurately measuring sample permeabilities in the range of 1×10^{-5} to 1×10^{-10} cm/s.

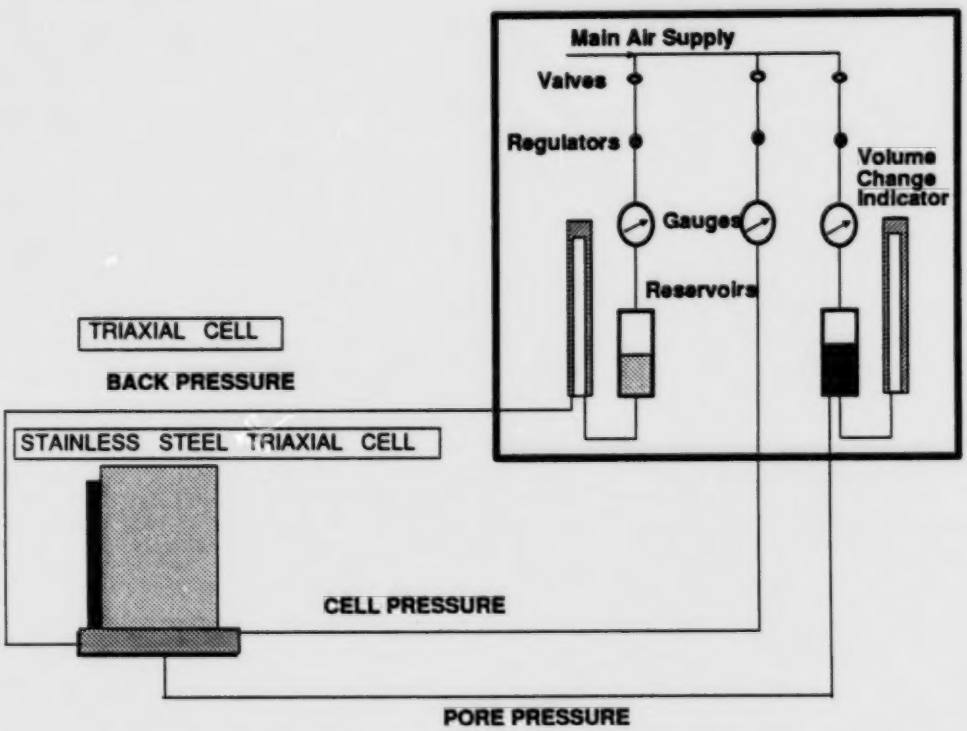

Figure 6.1
Triaxial Permeameter

The capability of determining permeability in this range is essential in evaluating the performance of different possible cover materials. Also, the laboratory test results obtained over short time periods must be precise in order to predict long-term performance.

This permeameter is also capable of determining volume change characteristics of samples during permeability testing. The pattern of the measured volume change provides an indication of changes in the structure of the sample. These changes may result in the development of cracks and fissures in the sample which may lead in turn to an increase in overall permeability.

This permeameter can simulate different stress conditions and hydraulic gradients. These parameters are controlled by varying the confining, pore and back pressure on the sample in triaxial permeameter.

7.0 PRESENTATION AND DISCUSSION OF TEST RESULTS

7.1 SAMPLE PREPARATION

In order to simulate field conditions for a hydraulically placed cover, the potash insolubles were mixed and prepared in a wet state. To maximize the effects of evaporation on the thin-layered insoluble admixtures, the rates of evaporation of water in the insoluble admixtures to evaporation rate of water were established. This was done to determine when successive layers could be placed. Results in this analysis are shown in Figures 7.1, 7.2, and 7.3. These figures show that very little further evaporation of the insoluble admixtures occurs after two days of drying.

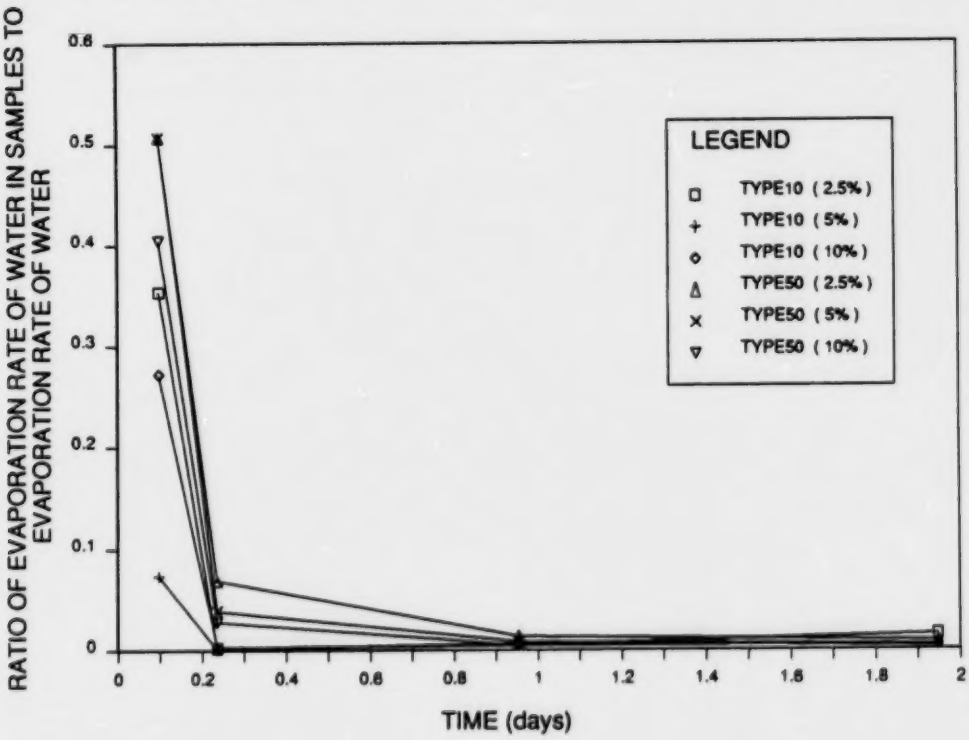

Figure 7.1
Evaportation Rate of Water in Sample from Type 10, and Type 50 Cement mixed with Insolubles to the Evaporation Rate of Water.

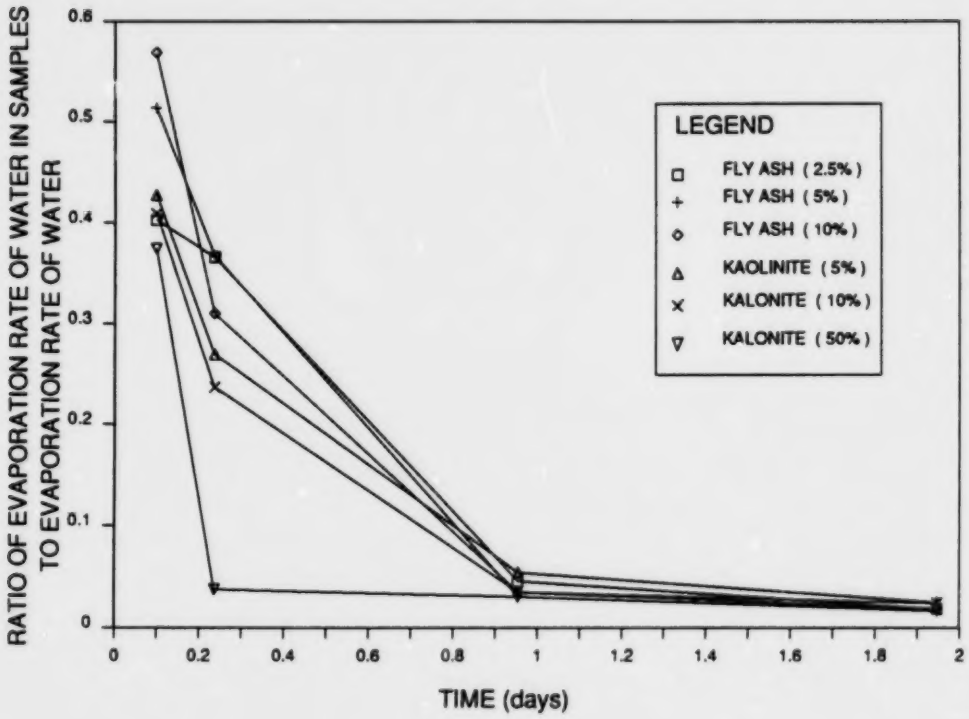

Figure 7.2
Evaporation Rate of Water In Samples from Flyash, and Kaolinite mixes with Insolubles to the Evaporation Rate for Water

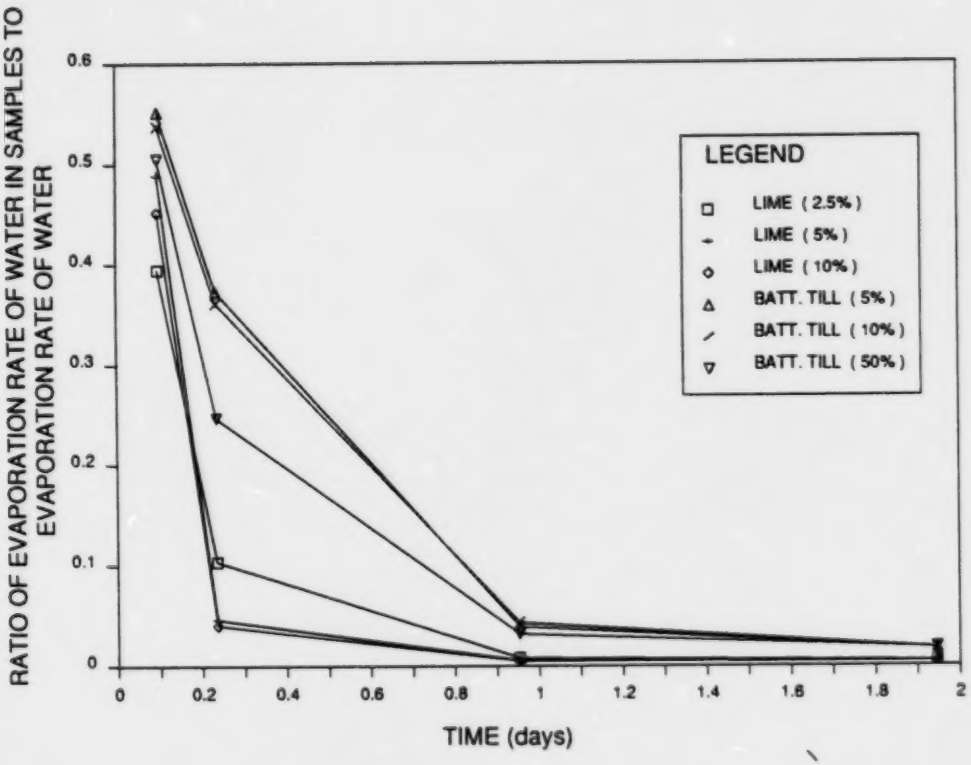

Figure 7.3
Evaportation Rate of Water in Samples from Battleford Till, and Lime mixed with Insolubles to the Evaporation Rate for Water.

Mr. W. Wilson (PhD graduate student) performed evaporation studies on sand, silt, clay, and potash insolubles in comparison to water over time. Results of this analysis are shown in Figure 7.4. The potash insolubles show very little to no evaporation loss after two days when compared to the clay and silt.

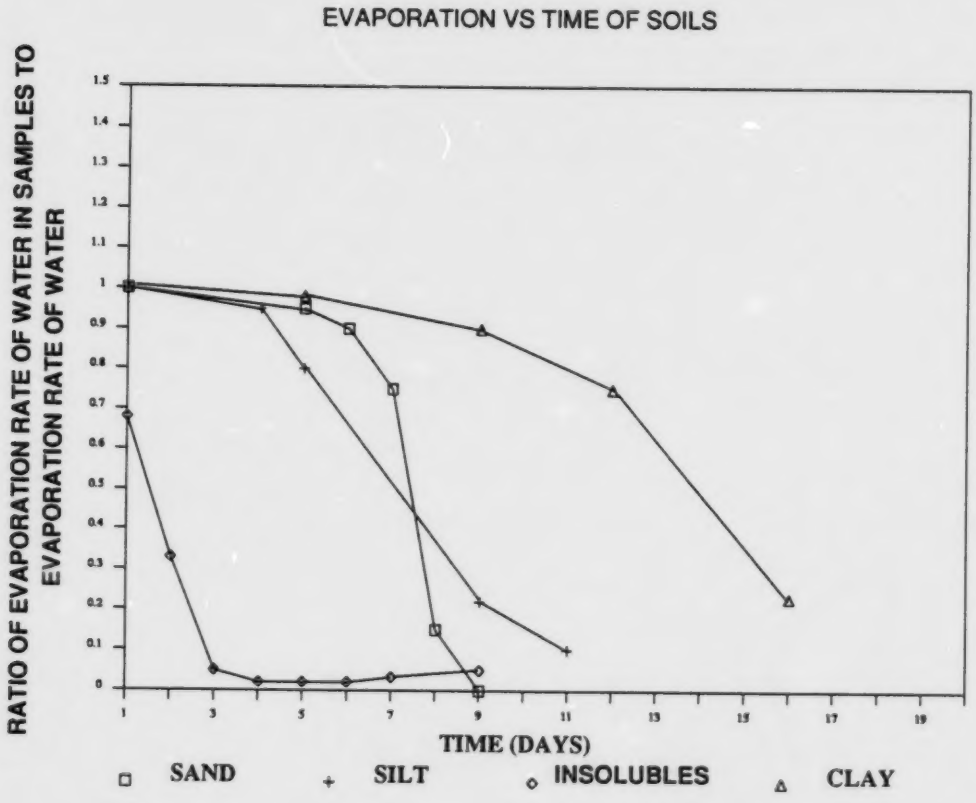

Figure 7.4
Evaporation Rate of Water in Silt, Clay, Sand, and Potash Insolubles Over the Evaporation Rate of Water with Time.

7.2 PHYSICAL PROPERTIES

Dry densities and moisture contents of the hydraulically placed admixed insolubles are presented in Table 7.1. A specific gravity of 2.78 was used for all insoluble admixtures.

Table 7.1
Summary of Physical Properties

ADMIXTURES	DRY DENSITY (kg/cm ^{3})	W/C (%)
Type 10 Cement 2.5% 5.0% 10.0%	1130	54
Type 50 Cement 2.5% 5.0% 10.0%	1270 1130 990	44 54 50
Battleford Till 5.0% 10.0% 50.0%		
Flyash 2.5% 5.0% 10.0%	1131	44
Kaolinite 2.5% 5.0% 10.0%	1230	44
Lime 2.5% 5.0% 10.0%		
Slime - Natural	1340	29
Slime - Washed	1070	37

7.3 PERMEABILITY

Permeability of the insoluble admixtures was determined using the one-dimensional constant head permeameter and by calculations from the one-dimensional consolidation test using the following formula:

$$K = C_v A_v \gamma_w / 1+e$$

where: C_v = coefficient of consolidation
A_v = coefficient of compressibility
$_w$ = unit weight of water
e = void ratio

Figure 7.5 is a typical permeability versus time plot for Type 10 cement at 10.0 percent. The permeability of the Type 50 and Type 10 cement at 10.0 percent was approximately 1.0×10^{-6} cm/s which is an order of magnitude lower than all other admixtures or natural and washed insolubles. Table 7.2 contains a summary of all permeability tests performed using the one-dimensional constant head permeameter. Detailed test results are located in Appendix A. The difference between the constant head permeameter and the calculated permeability is very small except for the natural and washed insolubles where the calculated values where approximately two orders of magnitude lower.

Prior to performing the permeability tests, all samples showed no signs of desiccation or shrinkage. Upon performing the tests with fresh water and removing some of the salt crystals the insoluble admixtures dryed and cracked as shown in Figure 7.6. This type of desication and cracking was similar to all samples tested although the cement admixtures took a longer period of time to dry.

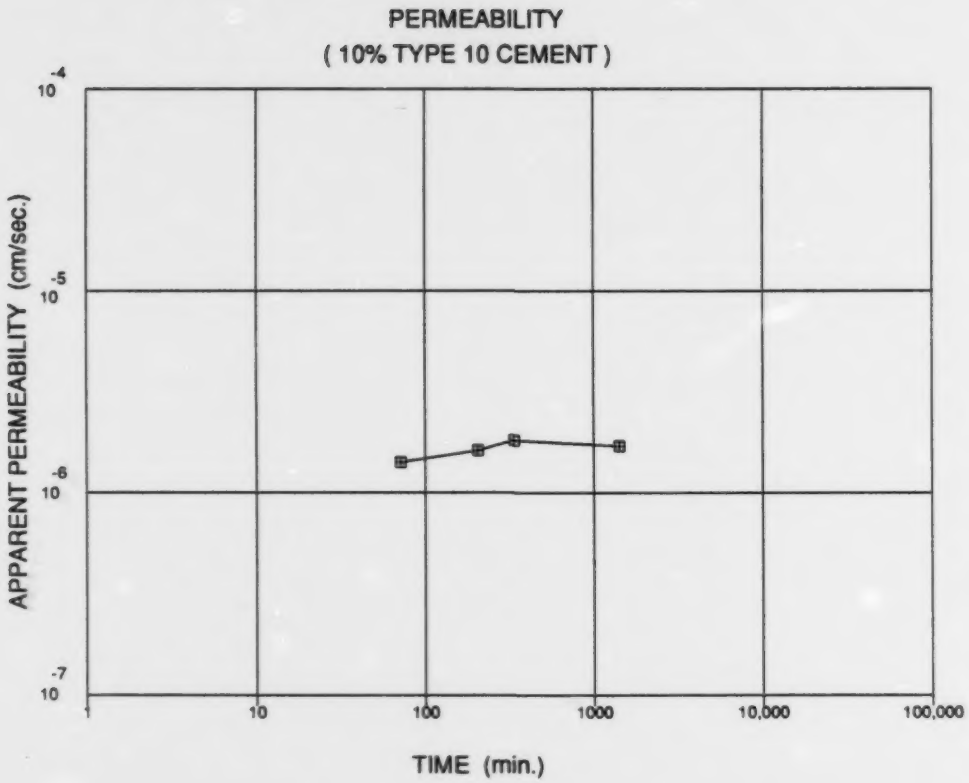

Figure 7.5
Typical Permeability Curve

Table 7.2
Permeability Test Results

ADMIXTURES	PERMEABILITY	
	CALCULATION (cm/sec)	CONSTANT HEAD (cm/sec)
Type 10 Cement		
2.5%	2×10^{-6}	
5.0%		
10.0%		2×10^{-6}
Type 50 Cement		
2.5%	1×10^{-6}	
5.0%	1×10^{-6}	
10.0%	2×10^{-6}	3×10^{-6}
Battleford Till		
5.0%		
10.0%		
50.0%		3×10^{-5}
Flyash		
2.5%		
5.0%	1×10^{-5}	
10.0%		
Kaolinite		
2.5%		
5.0%	3×10^{-6}	
10.0%		
Lime		
2.5%		
5.0%		
10.0%		3×10^{-5}
Slime - Natural	3×10^{-7}	3×10^{-5}
Slime - Washed	3×10^{-7}	9×10^{-6}

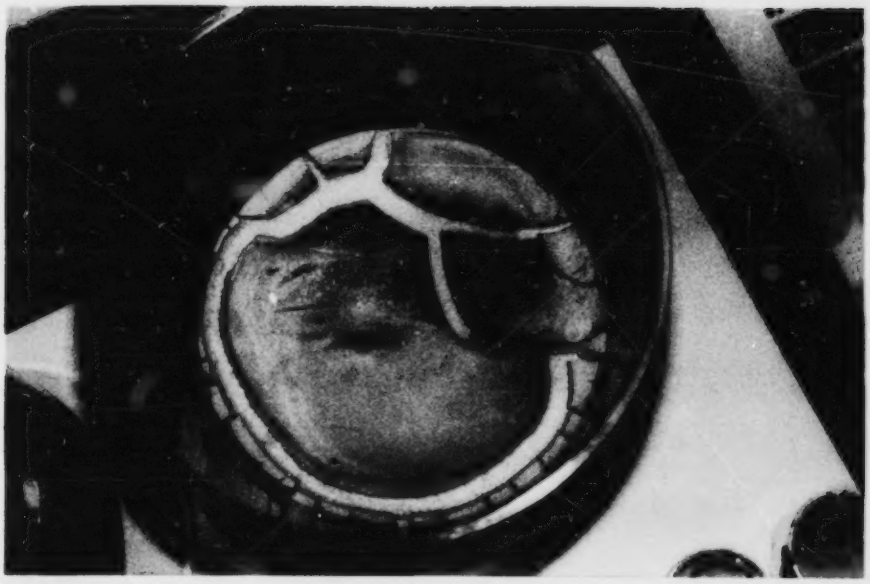

Figure 7.6
Desiccation Cracks in Sample

7.4 CONSOLIDATION TEST RESULTS

The consolidation log time graphical fitting method was used to analyze the one dimensional consolidation test results. Consolidation tests are presently still running and the values reported are subject to the completion of the tests. Results of the consolidation tests are summarized in Table 7.3. Detailed test results are presented in Appendix B. Density and void ratio of the samples varied from 990-1340 kg/cm^3 and 1.058-1.656 respectively. The coefficient of consolidation, C_v, were calculated at various times and stresses as shown in Appendix B. The values of C_v generally ranged from 1.5×10^{-4} cm^2/s to 5.0×10^{-4} cm^2/s.

The coefficient of permeability as determined by the consolidation method were comparable to those values from the constant head permeameter. An exception to this were the natural and washed insolubles as discussed in Section 7.3

Table 7.3
Summary of Consolidation Tests

ADMIXTURES	DENSITY (Kg/cm^3)	INITIAL/FINAL W.C (%)	INITIAL VOID RATIO	COEFF. OF CONSOLID. ($x10^{-4} cm^2/s$)
Type 10 Cement				
2.5%				
5.0%	1130	54 /	1.646	2.6
10.0%				
Type 50 Cement				
2.5%	1270	44 /	1.170	1.5
5.0%	1130	54 /	1.441	2.6
10.0%	990	50 /	1.656	1.9
Battleford Till				
5.0%				
10.0%				
50.0%				
Flyash				
2.5%				
5.0%	1131	44 /	1.308	4.9
10.0%				
Kaolinite				
2.5%				
5.0%	1230	44 /	1.193	1.5
10.0%				
Lime				
2.5%				
5.0%				
10.0%				
Slime - Natural	1340	29 /	1.058	4.0
Slime - Washed	1070	37 /	1.608	5.0

7.5 SHEAR STRENGTH

7.5.1 UNCONFINED COMPRESSIVE STRENGTH

The unconfined compression test could only be performed on the Type 50 and type 10 cement admixtures as the rest of the samples were too soft. Table 7.4 contains a summary of the ultimate shear strength as determined by the unconfined shear test. Appendix C contains detailed test results.

Table 7.4
Summary of Unconfined Compression Test

ADMIXTURES	ULTIMATE VERTICAL STRESS (kPa)
Type 10 Cement	
2.5%	5
5.0%	22
10.0%	68
Type 50 Cement	
2.5%	N/R
5.0%	N/R
10.0%	77

The results of this test indicate the the sample strength increases from that of a very soft to a stiff clay by increasing the cement content from 2.5 to 10.0 percent.

7.5.2 LABORATORY VANE SHEAR

One specimen from each of the admixed potash insolubles were tested using the laboratory vane shear. Shear strengths of the samples ranged from a low of 0.0 to 170 kPa a summary of laboratory vane shear test results are shown in Table 7.5.

Table 7.5
Summary of Laboratory Vane Shear Tests

ADMIXTURES	VANE SHEAR (kPa) DEPTH (mm)					
	0-15	15-30	30-45	45-60	60-75	75-90
Type 10 Cement						
2.5%	18	19	28	34	28	42
5.0%	47	50	36	57	105	102
10.0%	136	126	141	161	170	0
Type 50 Cement						
2.5%	35	22	31	31	42	41
5.0%	59	49	56	57	126	120
10.0%	147	156	115	120	-	-
Battleford Till						
5.0%	4	0	7	12	11	0
10.0%	0	5	9	13	10	0
50.0%	0	4	4	7	7	0
Flyash						
2.5%	0	7	4	10	10	-
5.0%	0	10	12	12	10	-
10.0%	4	9	10	13	0	-
Kaolinite						
5.0%	0	3	4	7	6	0
10.0%	0	4	0	5	6	0
50.0%	0	3	0	0	4	0
Lime						
2.5%	7	5	7	15	11	-
5.0%	0	0	5	3	-	-
10.0%	-	-	-	-	-	-
Slime - Natural	N/R					
Slime - Washed	N/R					

The only samples that had any real strength were the Type 50 and Type 10 cement admixtures. The shear strength increaesd with depth in these samples which corresponded to the length of curing time, as the older sample layers were closer to the bottome of the glass jar. The Battleford till, Flyash, Kaolinite and Lime admixtures would be classified as a soft to very soft clay soil whereas the cement admixtures would be classified as a moderaterly firm clay soil.

7.6 RETENTION CURVES

No retention curves could be determined at the time of this draft report. Tests are currently in progress and will be reported in an Addendum to this report.

8.0 CONCLUSIONS

1. The high salt content of the slimes formed a crust on surface of the slurried samples within approximately two day. This crust preventing significant further evaporation and desiccation of the samples.

2. In samples where the brine was washed out of the insolubles the samples dried more efficiently, however, these samples desiccated and cracked with the application of heat.

3. The cement modified mixtures produced a firm to stiff soil with permeabilities of approximately 1×10^{-6} cm/sec. However, the other admixtures remained soft and were an order of magnitude more permeable.

4. The findings indicate that typical soil admixtures such as glacial till, kaolinite, and fly ash appear to not represent a potential cover, especially if used in combination with the slimes.

5. The unwashed slimes generally gave the poorest results in this test program

6. Cement based admixtures gave the best results and may represent a possible solution to the the development of a suitable cover material for potash tailings.

9.0 FUTURE WORK

The primary goal of this phase is to evaluate the performane of the materials showing promise in the first phase. Thus, this phase will concentrate on testing to determine long-term permeability, flexibility and durability of the samples. This work will also begin to focus on the cement based slimes admixtures. However, some broad based testing will still be performed on other possible admixtures such as geopolymers.

A series of mix designs will be prepared using a wide range of cement, cement fumes, silica fumes and fly ash products in various percentages; mixed with washed and unwashed insolubles. The most promising of these admixtures will be tested in stainless steel triaxial permeameters. These permeameters are capable of accurately measuring hydraulic conductivity with time. They are also capable of interchanging the pore fluid to simulate different pore chemistry conditions. The equipment is also designed to measure the volume change of the sample during testing. This will provide an indication of problems which may develop as a result of the material shrinking or swelling. In addition to these advantages the equipment is also capable of handling samples up to 200 mm in diameter and operating with low confining pressures. This capability is important if the development of cracks and fissures with permeation is to be investigated.

Some additional work will also be carried out on existing slime deposits. The goal of this work is to determine the condition of these insolubles with respect to their possible use as a liner material. Some of the oldest deposits will be subjected to air-entry and sealed single ring infiltometer tests to determine their field permeability. Othes will be cored for subsequent testing in the laboratory.

The goal of this phase will be to set the stage for a possible field test program where the results of the laboratory program can be tested in the field.

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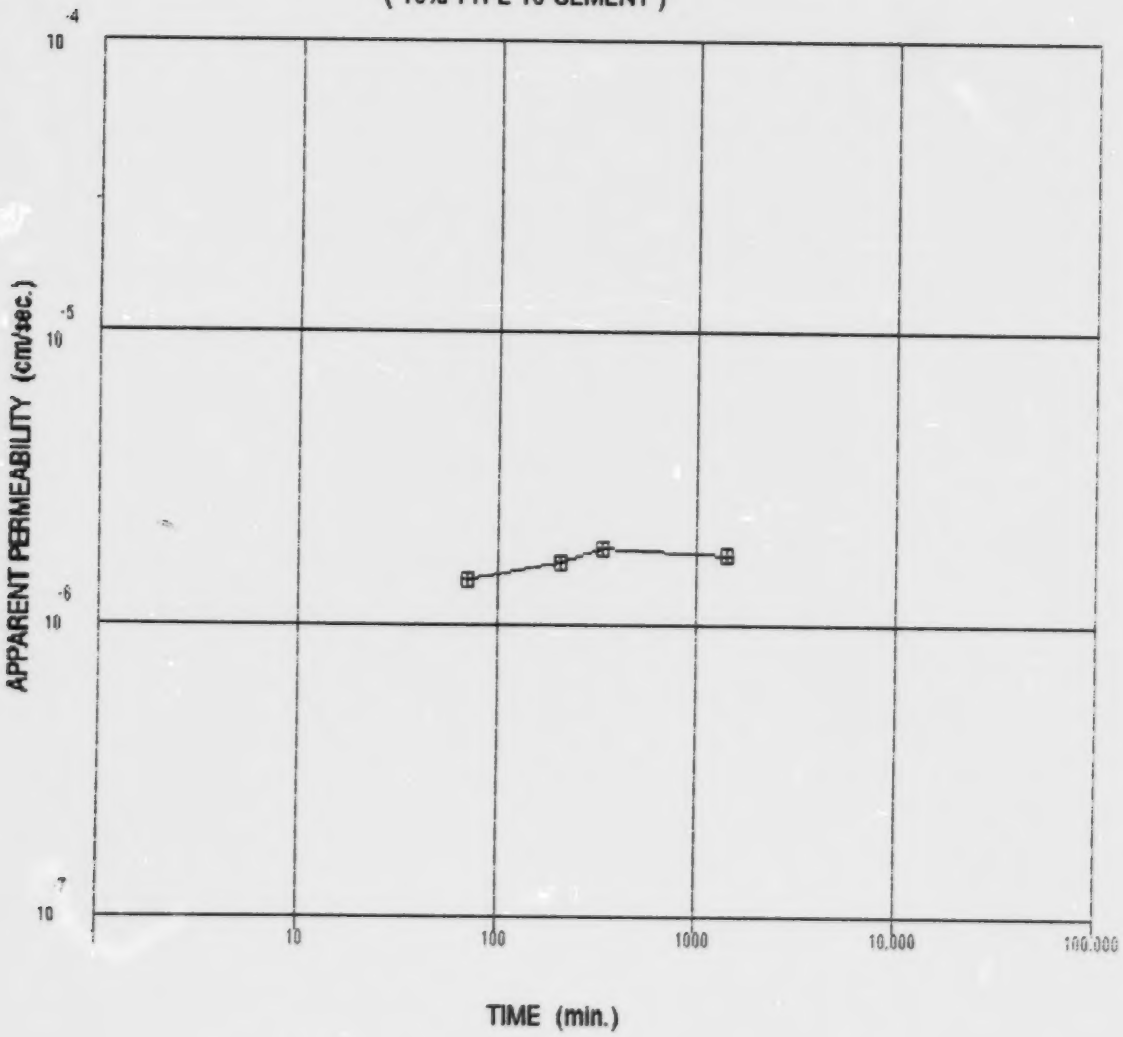
APPENDIX A

PERMEABILITY TEST RESULTS

PERMEABILITY

(10% TYPE 10 CEMENT)



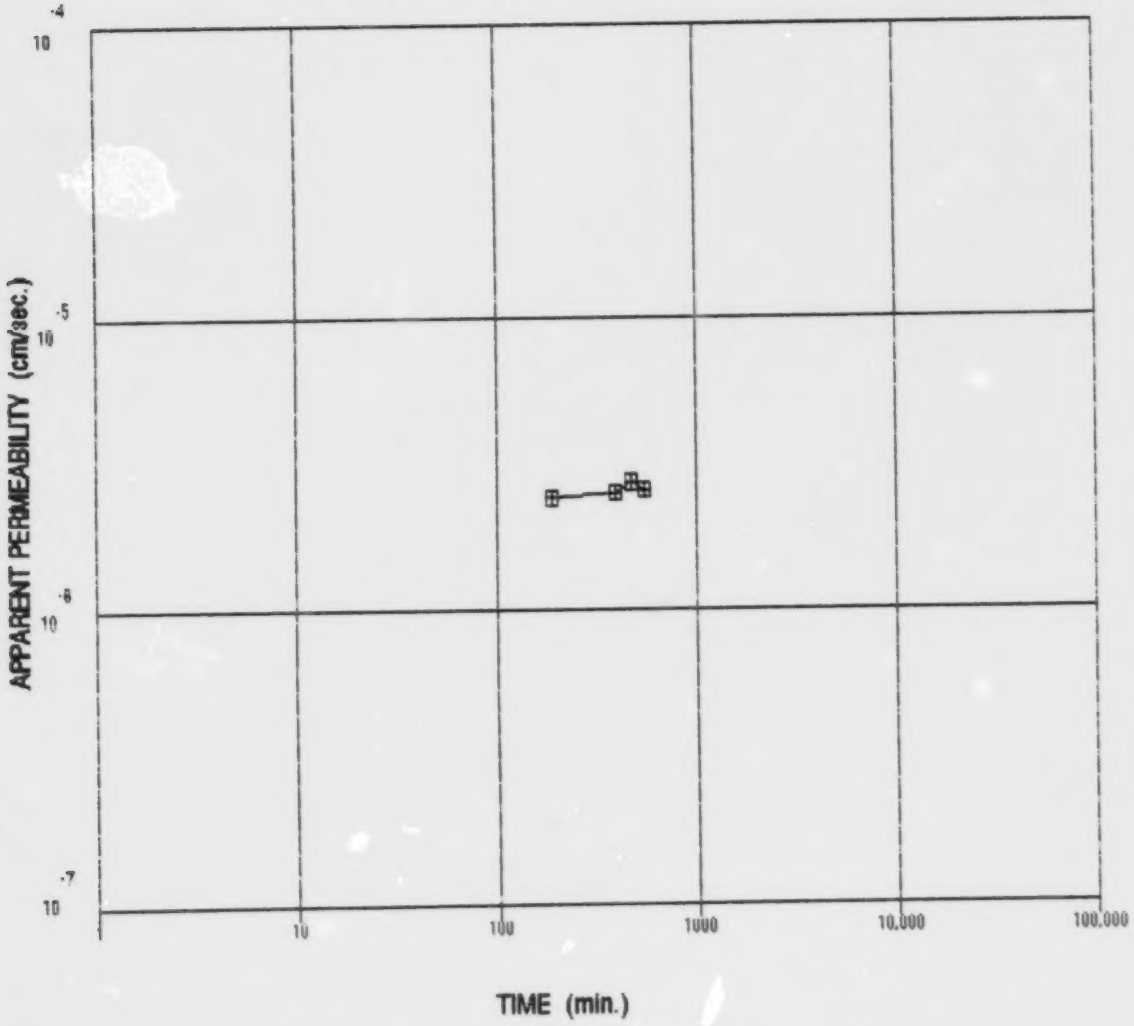
CONSTANT HEAD PERMEABILITY TEST

DATE:	MARCH 21/88	MATERIAL:	10% TYPE 10 CEMENT
DIAMETER (cm):	26.5	AREA (sq.cm):	551.55
HEAD:	6.97	thick (cm):	0.948
GRADIENT:	8.35		

TIME (min)	TARE INITIAL (g)	TARE FINAL (g)	WATER (cu.cm)	PERMEABILITY (cm/s)	TIME CUM (min)	COND (umhos)	CONC (ppm)
71	269.31	297.09	27.78	1.42E-06	71.0	324000	28000
134	269.93	330.3	60.37	1.63E-06	205.0	279000	24500
131	267.72	333.8	66.08	1.82E-06	336.0	220500	19000
1084	28.2	541.82	513.62	1.71E-06	1420.0		

PERMEABILITY

(10% TYPE 50 CEMENT)



CONSTANT HEAD PERMEABILITY TEST

DATE: MARCH 21/88 MATERIAL:10% TYPE 50 CEMENT

DIAMETER (cm): 26.6 AREA (sq. 555.72

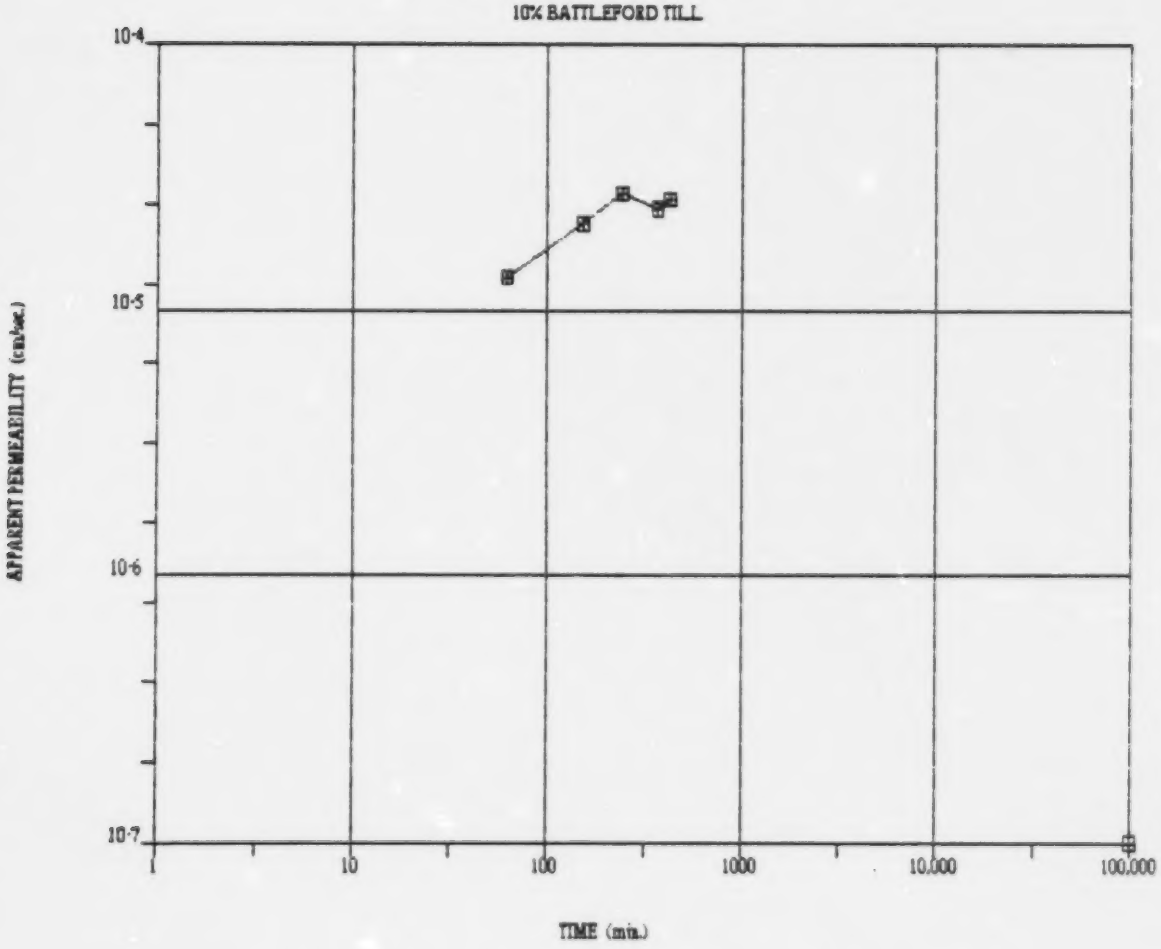
HEAD: 5.94 thick (cm 1.0725

GRADIENT: 6.54

TIME (min)	TARE INITIAL (g)	TARE FINAL (g)	WATER (cu.cm)	PERMEABILITY (cm/s)	TIME CUM (min)	COND (umhos)	CONC (ppm)
188	269.93	368.76	98.83	2.41E-06	188.0	N/R	N/R
208	266.33	380.65	114.32	2.52E-06	396.0	162000	14000
80	266.69	314.37	47.68	2.73E-06	476.0	108000	9000
73	266.37	307.04	40.67	2.56E-06	549.0	297000	27000

PERMEABILITY

10% BATTLEFORD TILL



CONSTANT HEAD PERMEABILITY TEST

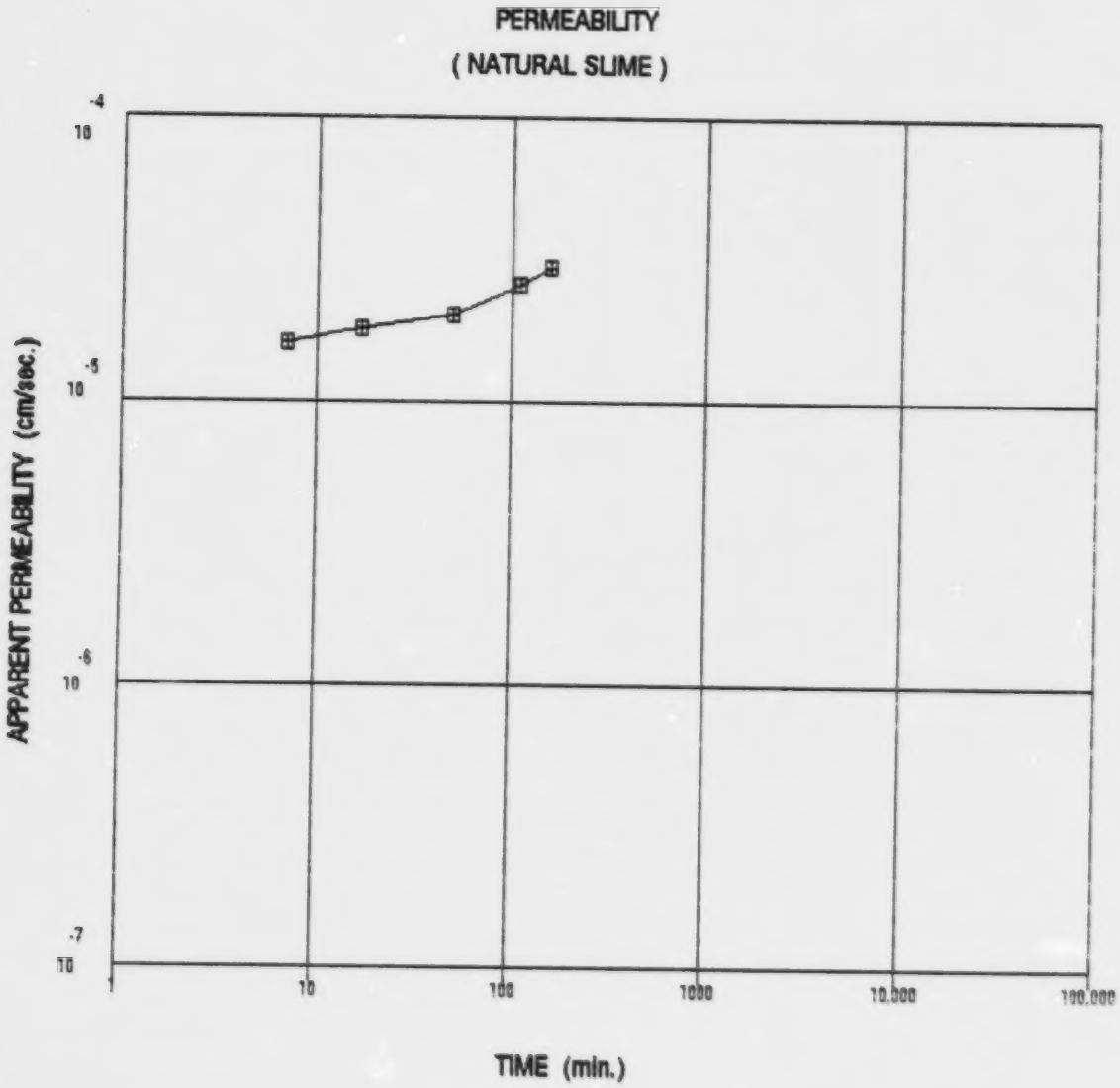
DATE: MARCH 24/88 MATERIAL:BATTLEFORD TILL

DIAMETER (cm): 26.6 AREA (sq. 555.72

HEAD: 6.38 thick (cm 1.428

GRADIENT: 5.47

TIME (min)	TARE INITIAL (g)	TARE FINAL (g)	WATER (cu.cm)	PERMEABILITY (cm/s)	TIME Cum (min)	COND (umhos)	CONC (ppm)
62	265.3	416.9	151.60	1.34E-05	62.0	N/R	
90	268.2	618.1	349.90	2.13E-05	152.0	N/R	
88	265.3	709.9	444.60	2.77E-05	240.0	N/R	
128	117.1	683.6	566.50	2.43E-05	368.0	N/R	
55	270	534.5	264.50	2.64E-05	423.0	N/R	


PERMEABILITY
(NATURAL SLIME)
APPARENT PERMEABILITY (cm/sec.)
10 -4
10 -5
10 -6
10 -7
1
10
100
1000
10,000
100,000
TIME (min.)

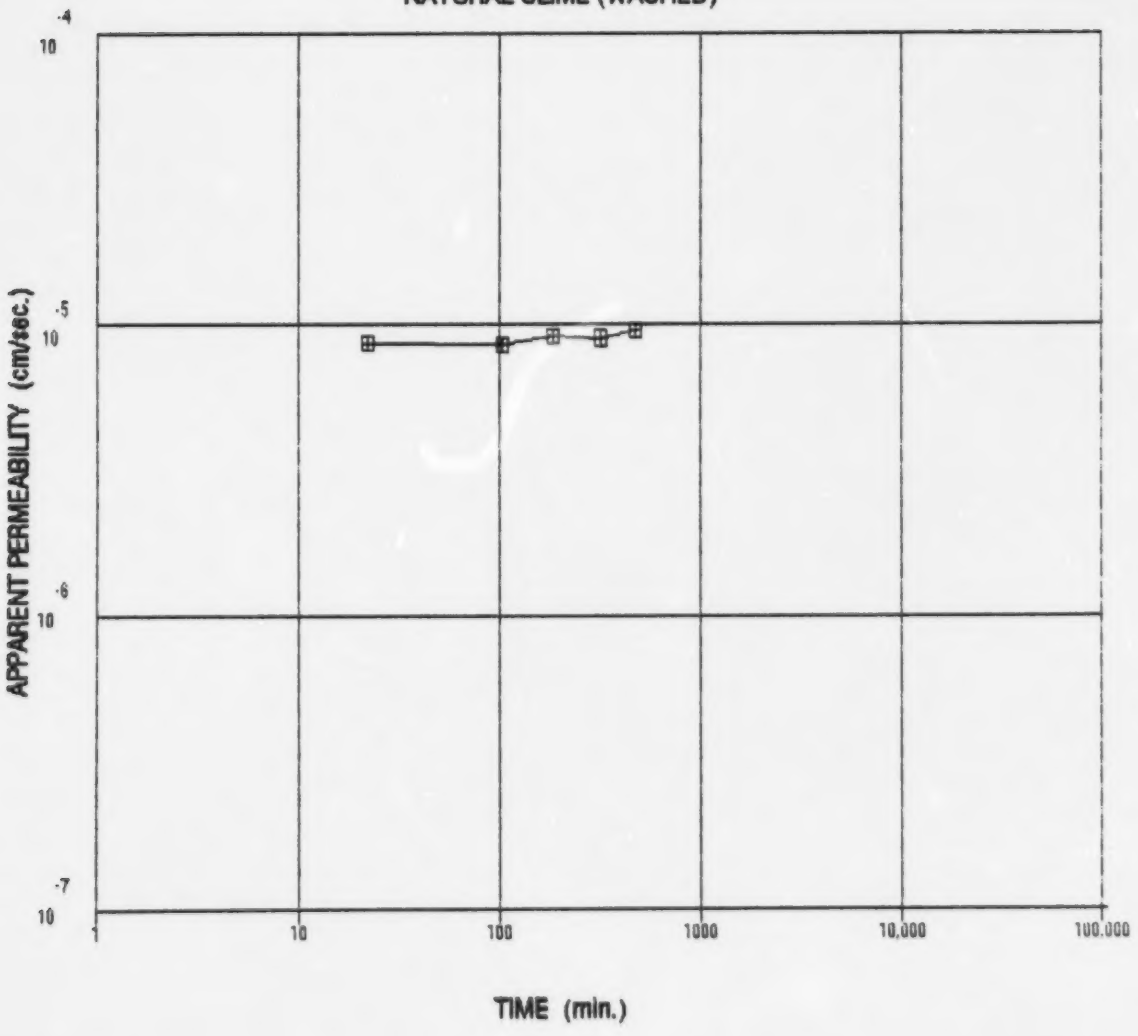
CONSTANT HEAD PERMEABILITY TEST

DATE:	MARCH 1/88	MATERIAL:	INSOLUBLES NATURAL
DIAMETER (cm):	26.8	AREA (sq.cm):	564.10
HEAD:	4.4	thick (cm):	2.5
GRADIENT:	2.76		

TIME (min)	TARE INITIAL (g)	TARE FINAL (g)	WATER (cu.cm)	PERMEABILITY (cm/s)	TIME CUM (min)	COND (umhos)	CONC (ppm)
7	270.02	280.4	10.44	1.60E-05	7.0	396000	35500
10	268.68	285.4	16.81	1.80E-05	17.0	313200	29000
33	265.33	327.7	62.42	2.02E-05	50.0	445500	39500
60	269.29	412.5	143.22	2.56E-05	110.0	313200	29000
48	266.31	398.1	131.81	2.94E-05	158.0	73800	7250

PERMEABILITY

NATURAL SLIME (WASHED)



CONSTANT HEAD PERMEABILITY TEST

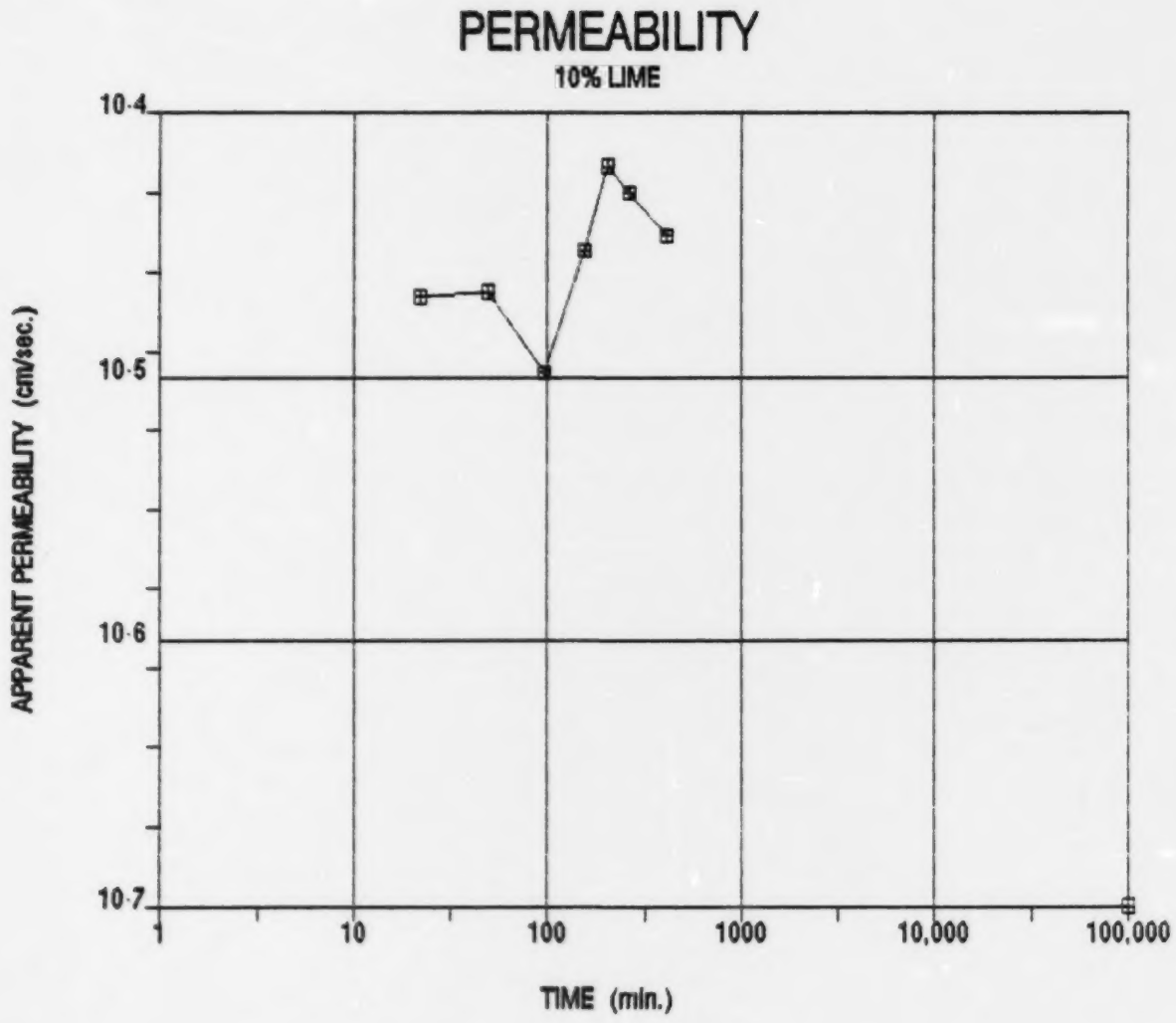
DATE: MARCH 26/88 MATERIAL: INSOLUBLES NATURAL (WASHED)

DIAMETER (cm): 26.8 AREA (sq.cm): 564.10

HEAD: 6.15 thick (cm): 1.91

GRADIENT: 4.22

TIME (min)	TARE INITIAL (g)	TARE FINAL (g)	WATER (cu.cm)	PERMEABILITY (cm/s)	TIME CUM (min)	COND (umhos)	CONC (ppm)
22	265.05	292.33	27.28	8.68E-06	22.0	N/R	N/R
82	265.65	365.98	100.33	8.57E-06	104.0	N/R	N/R
81	266.76	372.82	106.06	9.17E-06	185.0	N/R	N/R
137	270.00	446.51	176.51	9.02E-06	322.0	N/R	N/R
155	265.62	478.91	213.29	9.63E-06	477.0	N/R	N/R


PERMEABILITY
10% LIME
APPARENT PERMEABILITY (cm/sec.)
10-4
10-5
10-6
10-7
1
10
100
1000
10,000
100,000
TIME (min.)

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CONSTANT HEAD PERMEABILITY TEST

DATE:	MARCH 7/88	MATERIAL:	LIME 10.0%
DIAMETER (cm):	26.8	AREA (sq.cm):	564.10
HEAD:	4.4	thick (cm):	2.5
GRADIENT:	2.76		

TIME (min)	TARE INITIAL (g)	TARE FINAL (g)	WATER (cu.cm)	PERMEABILITY (cm/s)	TIME CUM (min)
22	262.92	304.92	42.00	2.04E-05	22.0
27	268.71	322.12	53.41	2.12E-05	49.0
47	265.37	311.43	46.06	1.05E-05	96.0
58	266.35	431.84	165.49	3.05E-05	154.0
51	267.42	568.73	301.31	6.32E-05	205.0
60	269.93	550.68	280.75	5.01E-05	265.0
143	269.79	731.7	461.91	3.46E-05	408.0

APPENDIX B

CONSOLIDATION TEST RESULTS

CONSOLIDATION SUMMARY SHEET

****

Sample No: 1
Description of Sample: Slime (Natural)
Number of Test Ring: #1

		At Beginning of Test		At End of Test
Wt. Wet Sample + Tare		219.93		##########
Wt. Dry Sample + Tare		##########		##########
Tare	(**ESTIMATED**)	81.00		##########
Weight of Water	Ww1=	30.86	Ww2=	ERR
Weight of Dry Soil		108.07		108.07
Water-Content (%)		28.56		ERR

Diameter of Test Ring = 6.38 cm. Area, A = 31.97 cm^2
Height of Sample at Beginning of Test, H1 = 2.53 cm.
Specific Gravity of Solids, G = 2.78
Weight of Dry Sample, Ws = 108.07 gm.
Reduced Height of Solids, Hs = 1.216 cm.
Change in Ht. of Sample From Beginning to the End of Test = ##########
Ht. of Sample at End of Test, H2 = ERR cm.
Ht. of Water at Beginning of Test, Hw1 = Ww1/A = 0.965 cm.
Ht. of Water at End of Test, Hw2 = Ww2/A = ERR cm.
Degree of Saturation at Beginning of Test, S1 = Hw1/(H1-Hs) = 0.735
Degree of Saturation at End of Test, S2 = Hw2/(H2-Hs) = ERR

Initial Void Ratio = (H1 - Hs)/ Hs = 1.081

Wt. of Stone and Cap = 490.20 gm. Mechanical Advantage = 8

LOAD (kg)	PRESSURE (kPa)	INITIAL DIAL READING (cm)	FINAL DIAL READING (cm)	CHANGE IN HEIGHT (cm)	VOID RATIO e	POROSITY n	DEFLECTION (cm)
0.490	1.50	1.727	1.700	-0.0270	1.058	0.514	-0.0270
0.228	7.09	3.805	3.728	-0.0774	0.995	0.499	-0.1044
0.445	12.43	3.728	3.660	-0.0678	0.939	0.484	-0.1722
0.909	23.83	3.650	3.535	-0.1150	0.844	0.458	-0.2872
1.818	46.12	3.534	3.420	-0.1135	0.751	0.429	-0.4007
3.336	83.40	3.420	3.293	-0.1275	0.646	0.393	-0.5282
6.937	171.79	3.293	3.176	-0.1170	0.550	0.355	-0.6452
13.536	333.79	3.275	3.247	-0.0280	0.527	0.345	-0.6732
#########	ERR	##################	ERR	ERR	ERR	ERR	
#########	ERR	##################	ERR	ERR	ERR	ERR	
#########	ERR	##################	ERR	ERR	ERR	ERR	
#########	ERR	##################	ERR	ERR	ERR	ERR	
#########	ERR	##################	ERR	ERR	ERR	ERR	
#########	ERR	##################	ERR	ERR	ERR	ERR	
#########	ERR	##################	ERR	ERR	ERR	ERR	
#########	ERR	##################	ERR	ERR	ERR	ERR	

#########	ERR	##################	ERR	ERR	ERR	ERR
#########	ERR	##################	ERR	ERR	ERR	ERR
#########	ERR	##################	ERR	ERR	ERR	ERR
#########	ERR	##################	ERR	ERR	ERR	ERR

COMPUTATION OF Cv AND k (LOG METHOD)

>>>T = 0.197 for 50% compression >>>> Cv = TH^2/t

Pressure (kPa)	Void Ratio	av	mv (m^2/kN)	H (cm)	t(50) (min)	Cv cm^2/sec	k (m/sec)
1.50	1.058	ERR	ERR	ERR	3.9	ERR	ERR
7.09	0.995	0.0109	0.0053	1.2321	10.0	4.98E-04	2.57E-07
12.43	0.939	0.0090	0.0043	1.1958	25.0	1.88E-04	7.95E-08
23.83	0.844	0.0056	0.0027	1.1502	10.0	4.34E-04	1.14E-07
46.12	0.751	0.0033	0.0016	1.0930	20.0	1.96E-04	3.08E-08
83.40	0.646	0.0016	0.0008	1.0328	19.0	1.84E-04	1.39E-08
171.79	0.550	0.0005	0.0002	0.9716	20.0	1.55E-04	3.48E-09
333.79	0.527	ERR	ERR	0.9354	6.0	4.79E-04	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR

CONSOLIDATION SUMMARY SHEET

****

Sample No: 2
Description of Sample: Slime (Washed)
Number of Test Ring: #2

		At Beginning of Test		At End of Test
Wt. Wet Sample + Tare		185.77		##########
Wt. Dry Sample + Tare		##########		##########
Tare		89.48		##########
Weight of Water	Ww1=	26.10	Ww2=	##########
Weight of Dry Soil		70.19		70.19
Water-Content (%)		37.19		ERR

Diameter of Test Ring = 6.39 cm. Area, A = 32.07 cm^2
Height of Sample at Beginning of Test, H1 = 2.05 cm.
Specific Gravity of Solids, G = 2.78
Weight of Dry Sample, Ws = 70.19 gm.
Reduced Height of Solids, Hs = 0.787 cm.
Change in Ht. of Sample From Beginning to the End of Test = ##########
Ht. of Sample at End of Test, H2 = ERR cm.
Ht. of Water at Beginning of Test, Hw1 = Ww1/A = 0.814 cm.
Ht. of Water at End of Test, Hw2 = Ww2/A = ERR cm.
Degree of Saturation at Beginning of Test, S1 = Hw1/(H1-Hs) = 0.645
Degree of Saturation at End of Test, S2 = Hw2/(H2-Hs) = ERR

Initial Void Ratio = (H1 - Hs)/ Hs = 1.604

Wt. of Stone and Cap = 511.65 gm. Mechanical Advantage = 8

LOAD (kg)	PRESSURE (kPa)	INITIAL DIAL READING (cm)	FINAL DIAL READING (cm)	CHANGE IN HEIGHT (cm)	VOID RATIO e	POROSITY n	DEFLECTION (cm)
0.089	0.27	0.528	0.532	0.0035	1.608	0.617	0.0035
0.512	1.57	0.481	0.389	-0.0920	1.491	0.599	-0.0885
0.227	7.12	0.484	0.326	-0.1580	1.291	0.563	-0.2465
0.454	12.68	0.326	0.166	-0.1600	1.088	0.521	-0.4065
0.901	23.62	0.154	0.019	-0.1345	0.917	0.478	-0.5410
1.809	45.84	0.948	0.908	-0.0400	0.866	0.464	-0.5810
3.624	90.25	0.908	0.808	-0.1000	0.739	0.425	-0.6810
6.851	169.22	0.807	0.724	-0.0830	0.633	0.388	-0.7640
13.466	331.10	0.724	0.642	-0.0820	0.529	0.346	-0.8460
26.812	657.71	0.643	0.570	-0.0725	0.437	0.304	-0.9185
#########	ERR	##########		ERR	ERR	ERR	ERR
#########	ERR	##########		ERR	ERR	ERR	ERR
#########	ERR	##########		ERR	ERR	ERR	ERR
#########	ERR	##########		ERR	ERR	ERR	ERR
#########	ERR	##########		ERR	ERR	ERR	ERR
#########	ERR	##########		ERR	ERR	ERR	ERR

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#########	ERR	##################	ERR	ERR	ERR	ERR
#########	ERR	##################	ERR	ERR	ERR	ERR
#########	ERR	##################	ERR	ERR	ERR	ERR

COMPUTATION OF Cv AND k (LOG METHOD)

>>>T = 0.197 for 50% compression >>>> Cv = TH^2/t

Pressure (kPa)	Void Ratio	av	mv (m^2/kN)	H (cm)	t(50) (min)	Cv cm^2/sec	k (m/sec)
0.27	1.608	ERR	ERR	ERR	1020.0	ERR	ERR
1.57	1.491	0.0464	0.0178	1.0038	6.0	5.51E-04	9.64E-07
7.12	1.291	0.0364	0.0140	0.9412	10.5	2.77E-04	3.79E-07
12.68	1.088	0.0227	0.0087	0.8617	2.2	1.11E-03	9.46E-07
23.62	0.917	0.0067	0.0026	0.7881	40.0	5.10E-05	1.28E-08
45.84	0.866	0.0027	0.0010	0.7445	6.2	2.94E-04	2.95E-08
90.25	0.739	0.0019	0.0007	0.7095	2.2	7.51E-04	5.33E-08
169.22	0.633	0.0009	0.0003	0.6637	4.1	3.53E-04	1.16E-08
331.10	0.529	0.0004	0.0002	0.6225	7.0	1.82E-04	2.75E-09
657.71	0.437	ERR	ERR	0.5839	2.2	5.09E-04	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
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ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR

CONSOLIDATION SUMMARY SHEET

****

Sample No: 4
Description of Sample: Type 50 - 10%
Number of Test Ring: #4

		At Beginning of Test		At End of Test
Wt. Wet Sample + Tare		204.88		##########
Wt. Dry Sample + Tare		##########		##########
Tare		78.17		##########
Weight of Water	Ww1=	42.24	Ww2=	ERR
Weight of Dry Soil		84.47		84.47
Water-Content (%) (**ESTIMATED**)		50.00		ERR

Diameter of Test Ring = 6.39 cm. Area, A = 32.07 cm^2
Height of Sample at Beginning of Test, H1 = 2.5214 cm.
Specific Gravity of Solids, G = 2.78
Weight of Dry Sample, Ws = 84.47 gm.
Reduced Height of Solids, Hs = 0.947 cm.
Change in Ht. of Sample From Beginning to the End of Test = ##########
Ht. of Sample at End of Test, H2 = ERR cm.
Ht. of Water at Beginning of Test, Hw1 = Ww1/A = 1.317 cm.
Ht. of Water at End of Test, Hw2 = Ww2/A = ERR cm.
Degree of Saturation at Beginning of Test, S1 = Hw1/(H1-Hs) = 0.837
Degree of Saturation at End of Test, S2 = Hw2/(H2-Hs) = ERR

Initial Void Ratio = (H1 - Hs)/ Hs = 1.661

Wt. of Stone and Cap = 484.20 gm. Mechanical Advantage = 8

LOAD (kg)	PRESSURE (kPa)	INITIAL DIAL READING (cm)	FINAL DIAL READING (cm)	CHANGE IN HEIGHT (cm)	VOID RATIO e	POROSITY n	DEFLECTION (cm)
0.104	0.32	0.906	0.901	-0.0045	1.656	0.624	-0.0045
0.484	1.48	0.217	0.207	-0.0100	1.646	0.622	-0.0145
0.227	7.04	0.943	0.911	-0.0315	1.613	0.617	-0.0460
0.455	12.61	0.910	0.904	-0.0062	1.606	0.616	-0.0522
0.910	23.74	0.904	0.895	-0.0090	1.597	0.615	-0.0612
1.818	45.97	0.895	0.880	-0.0150	1.581	0.613	-0.0762
3.632	90.36	0.879	0.838	-0.0410	1.537	0.606	-0.1172
6.769	167.12	0.960	0.824	-0.1360	1.394	0.582	-0.2532
13.383	328.99	0.824	0.528	-0.2955	1.082	0.520	-0.5487
26.592	652.24	0.528	0.235	-0.2932	0.773	0.436	-0.8419
#########	ERR	##########		ERR	ERR	ERR	ERR
#########	ERR	##########		ERR	ERR	ERR	ERR
#########	ERR	##########		ERR	ERR	ERR	ERR
#########	ERR	##########		ERR	ERR	ERR	ERR
#########	ERR	##########		ERR	ERR	ERR	ERR
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#########	ERR	##################	ERR	ERR	ERR	ERR
#########	ERR	##################	ERR	ERR	ERR	ERR
#########	ERR	##################	ERR	ERR	ERR	ERR

COMPUTATION OF Cv AND k (LOG METHOD)

>>>T = 0.197 for 50% compression >>>> Cv = TH^2/t

Pressure (kPa)	Void Ratio	av	mv (m^2/kN)	H (cm)	t(50) (min)	Cv cm^2/sec	k (m/sec)
0.32	1.656	ERR	ERR	ERR	1.0	ERR	ERR
1.48	1.646	0.0065	0.0024	1.2560	1.1	4.71E-03	1.13E-06
7.04	1.613	0.0036	0.0013	1.2456	20.0	2.55E-04	3.36E-08
12.61	1.606	0.0010	0.0004	1.2362	60.0	8.36E-05	2.96E-09
23.74	1.597	0.0008	0.0003	1.2324	20.0	2.49E-04	6.98E-09
45.97	1.581	0.0009	0.0003	1.2264	9.0	5.49E-04	1.79E-08
90.36	1.537	0.0015	0.0006	1.2124	70.0	6.89E-05	3.92E-09
167.12	1.394	0.0019	0.0007	1.1681	11.0	4.07E-04	2.87E-08
328.99	1.082	0.0013	0.0005	1.0602	9.0	4.10E-04	1.94E-08
652.24	0.773	ERR	ERR	0.9130	14.0	1.96E-04	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
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ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR

CONSOLIDATION SUMMARY SHEET

****

Sample No: 5
Description of Sample: Type 10 - 5%
Number of Test Ring: #5

		At Beginning of Test		At End of Test
Wt. Wet Sample + Tare		209.47		##########
Wt. Dry Sample + Tare		##########		##########
Tare		80.61		80.61
Weight of Water	Ww1=	45.50	Ww2=	ERR
Weight of Dry Soil		83.36		83.36
Water-Content (%)		54.58		ERR

Diameter of Test Ring = 6.378 cm. Area, A = 31.95 cm^2
Height of Sample at Beginning of Test, H1 = 2.49 cm.
Specific Gravity of Solids, G = 2.78
Weight of Dry Sample, Ws = 83.36 gm.
Reduced Height of Solids, Hs = 0.939 cm.
Change in Ht. of Sample From Beginning to the End of Test = ##########
Ht. of Sample at End of Test, H2 = ERR cm.
Ht. of Water at Beginning of Test, Hw1 = Ww1/A = 1.424 cm.
Ht. of Water at End of Test, Hw2 = Ww2/A = ERR cm.
Degree of Saturation at Beginning of Test, S1 = Hw1/(H1-Hs) = 0.918
Degree of Saturation at End of Test, S2 = Hw2/(H2-Hs) = ERR

Initial Void Ratio = (H1 - Hs)/ Hs = 1.653

Wt. of Stone and Cap = 534.80 gm. Mechanical Advantage = 8

LOAD (kg)	PRESSURE (kPa)	INITIAL DIAL READING (cm)	FINAL DIAL READING (cm)	CHANGE IN HEIGHT (cm)	VOID RATIO e	POROSITY n	DEFLECTION (cm)
0.535	1.64	0.513	0.506	-0.0066	1.646	0.622	-0.0066
0.227	7.21	0.298	0.258	-0.0403	1.603	0.616	-0.0469
0.454	12.80	0.248	0.167	-0.0810	1.517	0.603	-0.1279
0.910	23.99	0.167	0.129	-0.0378	1.476	0.596	-0.1657
1.364	35.15	0.129	0.117	-0.0122	1.464	0.594	-0.1779
1.790	45.61	1.117	0.979	-0.1379	1.317	0.568	-0.3158
3.605	90.21	0.975	0.714	-0.2615	1.038	0.509	-0.5773
6.815	169.04	1.004	0.797	-0.2070	0.817	0.450	-0.7843
13.442	331.83	0.797	0.577	-0.2200	0.583	0.368	-1.0043
26.671	656.79	0.577	0.402	-0.1745	0.397	0.284	-1.1788
#########	ERR	##########		ERR	ERR	ERR	ERR
#########	ERR	##########		ERR	ERR	ERR	ERR
#########	ERR	##########		ERR	ERR	ERR	ERR
#########	ERR	##########		ERR	ERR	ERR	ERR
#########	ERR	##########		ERR	ERR	ERR	ERR
#########	ERR	##########		ERR	ERR	ERR	ERR

#########	ERR	##################	ERR	ERR	ERR	ERR
#########	ERR	##################	ERR	ERR	ERR	ERR
#########	ERR	##################	ERR	ERR	ERR	ERR
#########	ERR	##################	ERR	ERR	ERR	ERR

COMPUTATION OF Cv AND k (LOG METHOD)

****

>>>T = 0.197 for 50% compression >>>> Cv = TH^2/t

Pressure (kPa)	Void Ratio	av	mv (m^2/kN)	H (cm)	t(50) (min)	Cv cm^2/sec	k (m/sec)
1.64	1.646	ERR	ERR	ERR	31.0	ERR	ERR
7.21	1.603	0.0116	0.0044	1.2316	0.9	5.53E-03	2.37E-06
12.80	1.517	0.0075	0.0028	1.2013	15.0	3.16E-04	8.81E-08
23.99	1.476	0.0024	0.0009	1.1716	30.0	1.50E-04	1.32E-08
35.15	1.464	0.0074	0.0028	1.1591	1.1	4.01E-03	1.10E-06
45.61	1.317	0.0077	0.0029	1.1216	105.0	3.93E-05	1.12E-08
90.21	1.038	0.0040	0.0015	1.0217	4.0	8.57E-04	1.28E-07
169.04	0.817	0.0019	0.0007	0.9046	5.0	5.37E-04	3.74E-08
331.83	0.583	0.0009	0.0003	0.7979	4.0	5.23E-04	1.67E-08
656.79	0.397	ERR	ERR	0.6992	6.0	2.68E-04	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR

CONSOLIDATION SUMMARY SHEET

****

Sample No: 6
Description of Sample: Type 50 - 2.5%
Number of Test Ring: 6

		At Beginning of Test		At End of Test
Wt. Wet Sample + Tare		212.72		##########
Wt. Dry Sample + Tare		##########		##########
Tare		80.75		80.75
Weight of Water	Ww1=	40.50	Ww2=	ERR
Weight of Dry Soil		91.47		91.47
Water-Content (%)		44.27		ERR

Diameter of Test Ring = 6.386 cm. Area, A = 32.03 cm^2
Height of Sample at Beginning of Test, H1 = 2.245 cm.
Specific Gravity of Solids, G = 2.78
Weight of Dry Sample, Ws = 91.47 gm.
Reduced Height of Solids, Hs = 1.027 cm.
Change in Ht. of Sample From Beginning to the End of Test = ##########
Ht. of Sample at End of Test, H2 = ERR cm.
Ht. of Water at Beginning of Test, Hw1 = Ww1/A = 1.264 cm.
Ht. of Water at End of Test, Hw2 = Ww2/A = ERR cm.
Degree of Saturation at Beginning of Test, S1 = Hw1/(H1-Hs) = 1.038
Degree of Saturation at End of Test, S2 = Hw2/(H2-Hs) = ERR

Initial Void Ratio = (H1 - Hs)/ Hs = 1.185

Wt. of Stone and Cap = 520.90 gm. Mechanical Advantage = 8

LOAD (kg)	PRESSURE (kPa)	INITIAL DIAL READING (cm)	FINAL DIAL READING (cm)	CHANGE IN HEIGHT (cm)	VOID RATIO e	POROSITY n	DEFLECTION (cm)
0.521	1.60	1.782	1.766	-0.0158	1.170	0.539	-0.0158
0.227	7.15	1.557	1.543	-0.0140	1.156	0.536	-0.0298
0.454	12.72	1.543	1.484	-0.0588	1.099	0.524	-0.0886
0.909	23.86	1.484	1.381	-0.1031	0.999	0.500	-0.1917
1.817	46.12	1.378	1.207	-0.1715	0.832	0.454	-0.3632
3.632	90.60	1.207	1.017	-0.1895	0.647	0.393	-0.5527
6.856	169.59	1.013	0.802	-0.2105	0.442	0.307	-0.7632
13.485	332.02	0.802	0.627	-0.1750	0.272	0.214	-0.9382
26.805	658.39	0.627	0.459	-0.1675	0.109	0.098	-1.1057
#########	ERR	##########	ERR	ERR	ERR	ERR	ERR
#########	ERR	##########	ERR	ERR	ERR	ERR	ERR
#########	ERR	##########	ERR	ERR	ERR	ERR	ERR
#########	ERR	##########	ERR	ERR	ERR	ERR	ERR
#########	ERR	##########	ERR	ERR	ERR	ERR	ERR
#########	ERR	##########	ERR	ERR	ERR	ERR	ERR
#########	ERR	##########	ERR	ERR	ERR	ERR	ERR

########	ERR	##################	ERR	ERR	ERR	ERR	
########	ERR	##################	ERR	ERR	ERR	ERR	
########	ERR	##################	ERR	ERR	ERR	ERR	
########	ERR	##################	ERR	ERR	ERR	ERR	

COMPUTATION OF Cv AND k (LOG METHOD)

****

>>>T = 0.197 for 50% compression >>>> Cv = TH^2/t

Pressure (kPa)	Void Ratio	av	mv (m^2/kN)	H (cm)	t(50) (min)	Cv cm^2/sec	k (m/sec)
1.60	1.170	ERR	ERR	ERR	12.0	ERR	ERR
7.15	1.156	0.0064	0.0029	1.1111	15.0	2.70E-04	7.73E-08
12.72	1.099	0.0094	0.0043	1.0929	60.0	6.54E-05	2.77E-08
23.86	0.999	0.0080	0.0037	1.0524	1.2	3.03E-03	1.09E-06
46.12	0.832	0.0053	0.0024	0.9838	3.5	9.08E-04	2.15E-07
90.60	0.647	0.0032	0.0014	0.8935	5.0	5.24E-04	7.42E-08
169.59	0.442	0.0016	0.0007	0.7935	4.0	5.17E-04	3.61E-08
332.02	0.272	0.0007	0.0003	0.6972	4.5	3.55E-04	1.09E-08
658.39	0.109	ERR	ERR	0.6115	8.0	1.53E-04	ERR
ERR	ERR	ERR	ERR	ERR	########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	########	ERR	ERR

CONSOLIDATION SUMMARY SHEET

****

Sample No: 8
Description of Sample: Type 50 - 5%
Number of Test Ring: #8

		At Beginning of Test		At End of Test
Wt. Wet Sample + Tare		212.74		##########
Wt. Dry Sample + Tare		##########		##########
Tare		82.42		##########
Weight of Water	Ww1=	45.56	Ww2=	ERR
Weight of Dry Soil		84.76		84.76
Water-Content (%)		53.76		ERR

Diameter of Test Ring = 6.388 cm. Area, A = 32.05 cm^2
Height of Sample at Beginning of Test, H1 = 2.33 cm.
Specific Gravity of Solids, G = 2.78
Weight of Dry Sample, Ws = 84.76 gm.
Reduced Height of Solids, Hs = 0.951 cm.
Change in Ht. of Sample From Beginning to the End of Test = ##########
Ht. of Sample at End of Test, H2 = ERR cm.
Ht. of Water at Beginning of Test, Hw1 = Ww1/A = 1.422 cm.
Ht. of Water at End of Test, Hw2 = Ww2/A = ERR cm.
Degree of Saturation at Beginning of Test, S1 = Hw1/(H1-Hs) = 1.031
Degree of Saturation at End of Test, S2 = Hw2/(H2-Hs) = ERR

Initial Void Ratio = (H1 - Hs)/ Hs = 1.449

Wt. of Stone and Cap = 479.80 gm. Mechanical Advantage = 8

LOAD (kg)	PRESSURE (kPa)	INITIAL DIAL READING (cm)	FINAL DIAL READING (cm)	CHANGE IN HEIGHT (cm)	VOID RATIO e	POROSITY n	DEFLECTION (cm)
0.480	1.47	0.812	0.804	-0.0080	1.441	0.590	-0.0080
0.227	7.03	0.595	0.589	-0.0055	1.435	0.589	-0.0135
0.455	12.60	0.589	0.580	-0.0095	1.425	0.588	-0.0230
0.909	23.73	0.580	0.558	-0.0214	1.403	0.584	-0.0444
1.817	45.97	0.558	0.490	-0.0679	1.331	0.571	-0.1123
3.632	90.41	0.488	0.339	-0.1490	1.175	0.540	-0.2613
6.811	168.25	0.339	0.147	-0.1920	0.973	0.493	-0.4533
13.423	330.16	1.147	0.898	-0.2485	0.712	0.416	-0.7018
26.698	655.23	0.896	0.679	-0.2164	0.484	0.326	-0.9182
#########	ERR	##########		ERR	ERR	ERR	ERR
#########	ERR	##########		ERR	ERR	ERR	ERR
#########	ERR	##########		ERR	ERR	ERR	ERR
#########	ERR	##########		ERR	ERR	ERR	ERR
#########	ERR	##########		ERR	ERR	ERR	ERR
#########	ERR	##########		ERR	ERR	ERR	ERR
#########	ERR	##########		ERR	ERR	ERR	ERR

#########	ERR	##################	ERR	ERR	ERR	ERR
#########	ERR	##################	ERR	ERR	ERR	ERR
#########	ERR	##################	ERR	ERR	ERR	ERR
#########	ERR	##################	ERR	ERR	ERR	ERR

COMPUTATION OF Cv AND k (LOG METHOD)

****

>>>T = 0.197 for 50% compression >>>> Cv = TH^2/t

Pressure (kPa)	Void Ratio	av	mv (m^2/kN)	H (cm)	t(50) (min)	Cv cm^2/sec	k (m/sec)
1.47	1.441	ERR	ERR	ERR	36.0	ERR	ERR
7.03	1.435	0.0014	0.0006	1.1596	8.0	5.52E-04	3.13E-08
12.60	1.425	0.0019	0.0008	1.1559	17.0	2.58E-04	2.01E-08
23.73	1.403	0.0028	0.0011	1.1482	9.0	4.81E-04	5.42E-08
45.97	1.331	0.0034	0.0014	1.1258	4.5	9.25E-04	1.27E-07
90.41	1.175	0.0029	0.0012	1.0716	3.8	9.92E-04	1.16E-07
168.25	0.973	0.0019	0.0008	0.9864	7.0	4.56E-04	3.53E-08
330.16	0.712	0.0010	0.0004	0.8762	5.0	5.04E-04	2.03E-08
655.23	0.484	ERR	ERR	0.7600	7.2	2.63E-04	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR

CONSOLIDATION SUMMARY SHEET

****

Sample No: 13
Description of Sample: Kalonite - 5%
Number of Test Ring: #13

		At Beginning of Test		At End of Test
Wt. Wet Sample + Tare		177.99		##########
Wt. Dry Sample + Tare		##########		##########
Tare		80.54		##########
Weight of Water	Ww1=	29.79	Ww2=	ERR
Weight of Dry Soil		67.66		67.66
Water-Content (%)		44.02		ERR

Diameter of Test Ring = 6.34 cm. Area, A = 31.57 cm^2
Height of Sample at Beginning of Test, H1 = 1.743 cm.
Specific Gravity of Solids, G = 2.78
Weight of Dry Sample, Ws = 67.66 gm.
Reduced Height of Solids, Hs = 0.771 cm.
Change in Ht. of Sample From Beginning to the End of Test = ##########
Ht. of Sample at End of Test, H2 = ERR cm.
Ht. of Water at Beginning of Test, Hw1 = Ww1/A = 0.943 cm.
Ht. of Water at End of Test, Hw2 = Ww2/A = ERR cm.
Degree of Saturation at Beginning of Test, S1 = Hw1/(H1-Hs) = 0.971
Degree of Saturation at End of Test, S2 = Hw2/(H2-Hs) = ERR

Initial Void Ratio = (H1 - Hs)/ Hs = 1.261

Wt. of Stone and Cap = 521.45 gm. Mechanical Advantage = 8

LOAD (kg)	PRESSURE (kPa)	INITIAL DIAL READING (cm)	FINAL DIAL READING (cm)	CHANGE IN HEIGHT (cm)	VOID RATIO e	POROSITY n	DEFLECTION (cm)
0.135	0.42	0.460	0.407	-0.0527	1.193	0.544	-0.0527
0.521	1.62	1.779	1.675	-0.1045	1.057	0.514	-0.1572
0.228	7.28	1.079	0.960	-0.1190	0.903	0.474	-0.2762
0.683	18.59	1.960	1.844	-0.1165	0.752	0.429	-0.3927
1.582	40.94	1.844	1.749	-0.0950	0.628	0.386	-0.4877
2.715	69.11	1.749	1.655	-0.0940	0.506	0.336	-0.5817
5.899	148.27	1.655	1.572	-0.0830	0.399	0.285	-0.6647
########	ERR	##########	ERR	ERR	ERR	ERR	ERR
########	ERR	##########	ERR	ERR	ERR	ERR	ERR
########	ERR	##########	ERR	ERR	ERR	ERR	ERR
########	ERR	##########	ERR	ERR	ERR	ERR	ERR
########	ERR	##########	ERR	ERR	ERR	ERR	ERR
########	ERR	##########	ERR	ERR	ERR	ERR	ERR
########	ERR	##########	ERR	ERR	ERR	ERR	ERR
########	ERR	##########	ERR	ERR	ERR	ERR	ERR
########	ERR	##########	ERR	ERR	ERR	ERR	ERR

########	ERR	##################	ERR	ERR	ERR	ERR
########	ERR	##################	ERR	ERR	ERR	ERR
########	ERR	##################	ERR	ERR	ERR	ERR
########	ERR	##################	ERR	ERR	ERR	ERR

COMPUTATION OF Cv AND k (LOG METHOD)

****

>>>T = 0.197 for 50% compression >>>> Cv = TH^2/t

Pressure (kPa)	Void Ratio	av	mv (m^2/kN)	H (cm)	t(50) (min)	Cv cm^2/sec	k (m/sec)
0.42	1.193	ERR	ERR	ERR	2.2	ERR	ERR
1.62	1.057	0.0423	0.0187	0.8190	12.0	1.84E-04	3.37E-07
7.28	0.903	0.0180	0.0080	0.7632	9.0	2.12E-04	1.66E-07
18.59	0.752	0.0082	0.0036	0.7043	3.1	5.25E-04	1.86E-07
40.94	0.628	0.0049	0.0021	0.6514	3.0	4.64E-04	9.78E-08
69.11	0.506	0.0021	0.0009	0.6042	4.5	2.66E-04	2.47E-08
148.27	0.399	ERR	ERR	0.5599	6.5	1.58E-04	ERR
ERR	ERR	ERR	ERR	ERR	########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	########	ERR	ERR

CONSOLIDATION SUMMARY SHEET

****

Sample No: 14
Description of Sample: Flyash - 5%
Number of Test Ring: #14

		At Beginning of Test		At End of Test
Wt. Wet Sample + Tare		197.32		##########
Wt. Dry Sample + Tare		##########		##########
Tare (***ESTIMATED***)		81.00		81.00
Weight of Water	Ww1=	35.46	Ww2=	ERR
Weight of Dry Soil		80.86		80.86
Water-Content (%)		43.86		ERR

Diameter of Test Ring = 6.36 cm. Area, A = 31.77 cm^2
Height of Sample at Beginning of Test, H1 = 2.25 cm.
Specific Gravity of Solids, G = 2.78
Weight of Dry Sample, Ws = 80.86 gm.
Reduced Height of Solids, Hs = 0.916 cm.
Change in Ht. of Sample From Beginning to the End of Test = #.########
Ht. of Sample at End of Test, H2 = ERR cm.
Ht. of Water at Beginning of Test, Hw1 = Ww1/A = 1.116 cm.
Ht. of Water at End of Test, Hw2 = Ww2/A = ERR cm.
Degree of Saturation at Beginning of Test, S1 = Hw1/(H1-Hs) = 0.837
Degree of Saturation at End of Test, S2 = Hw2/(H2-Hs) = ERR

Initial Void Ratio = (H1 - Hs)/ Hs = 1.458

Wt. of Stone and Cap = 507.30 gm. Mechanical Advantage = 8

LOAD (kg)	PRESSURE (kPa)	INITIAL DIAL READING (cm)	FINAL DIAL READING (cm)	CHANGE IN HEIGHT (cm)	VOID RATIO e	POROSITY n	DEFLECTION (cm)
0.087	0.03	0.198	0.061	-0.1370	1.308	0.567	-0.1370
0.507	1.57	1.025	0.918	-0.1075	1.190	0.543	-0.2445
0.227	7.17	0.678	0.572	-0.1060	1.075	0.518	-0.3505
0.672	18.17	0.572	0.425	-0.1465	0.915	0.478	-0.4970
1.582	40.65	0.425	0.305	-0.1205	0.783	0.439	-0.6175
3.381	85.09	0.304	0.151	-0.1525	0.617	0.381	-0.7700
#########	ERR	##################	ERR	ERR	ERR	ERR	
#########	ERR	##################	ERR	ERR	ERR	ERR	
#########	ERR	##################	ERR	ERR	ERR	ERR	
#########	ERR	##################	ERR	ERR	ERR	ERR	
#########	ERR	##################	ERR	ERR	ERR	ERR	
#########	ERR	##################	ERR	ERR	ERR	ERR	
#########	ERR	##################	ERR	ERR	ERR	ERR	
#########	ERR	##################	ERR	ERR	ERR	ERR	
#########	ERR	##################	ERR	ERR	ERR	ERR	
#########	ERR	##################	ERR	ERR	ERR	ERR	

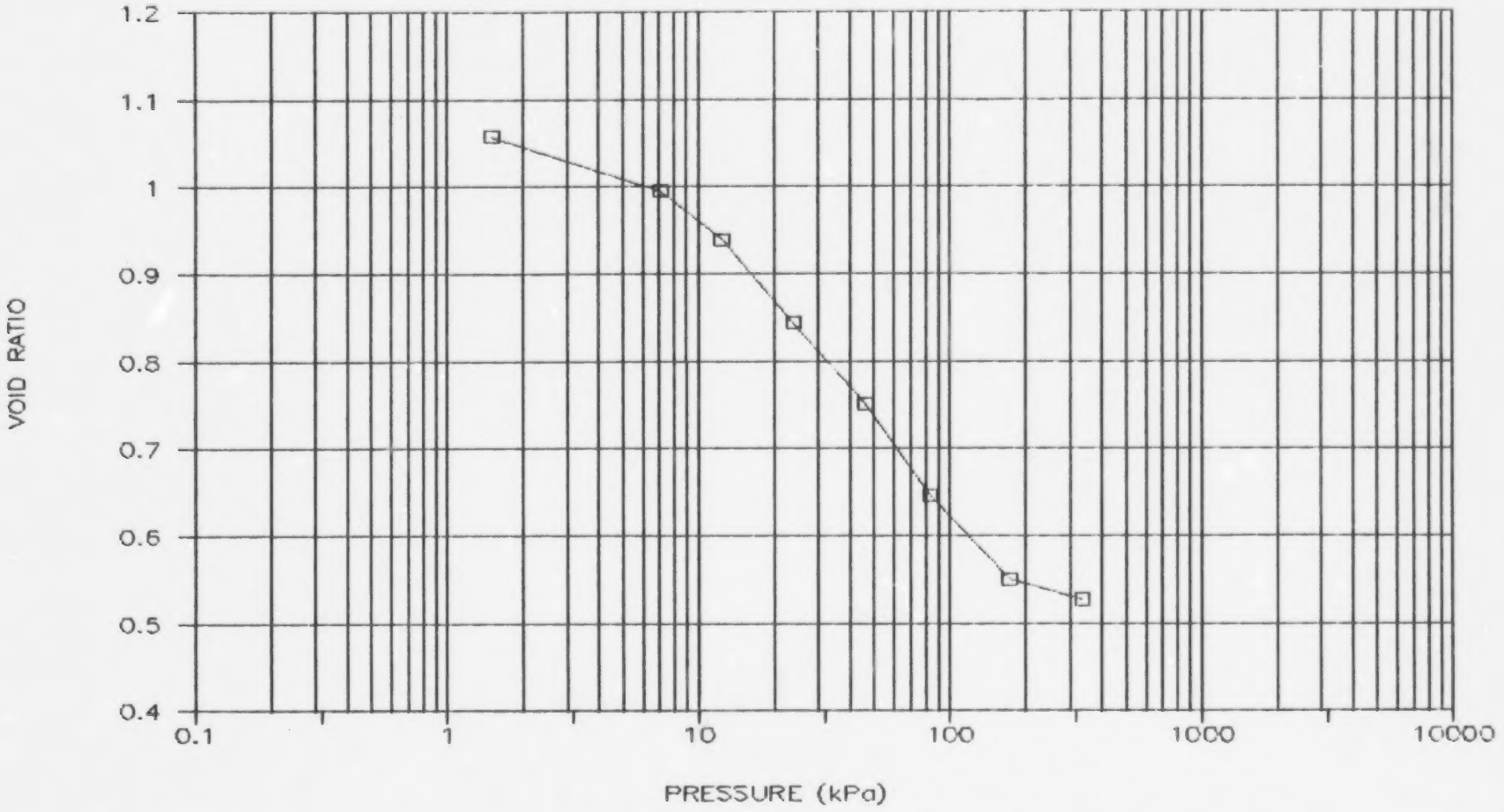
#########	ERR	##################	ERR	ERR	ERR	ERR	
#########	ERR	##################	ERR	ERR	ERR	ERR	
#########	ERR	##################	ERR	ERR	ERR	ERR	
#########	ERR	##################	ERR	ERR	ERR	ERR	

COMPUTATION OF Cv AND k (LOG METHOD)

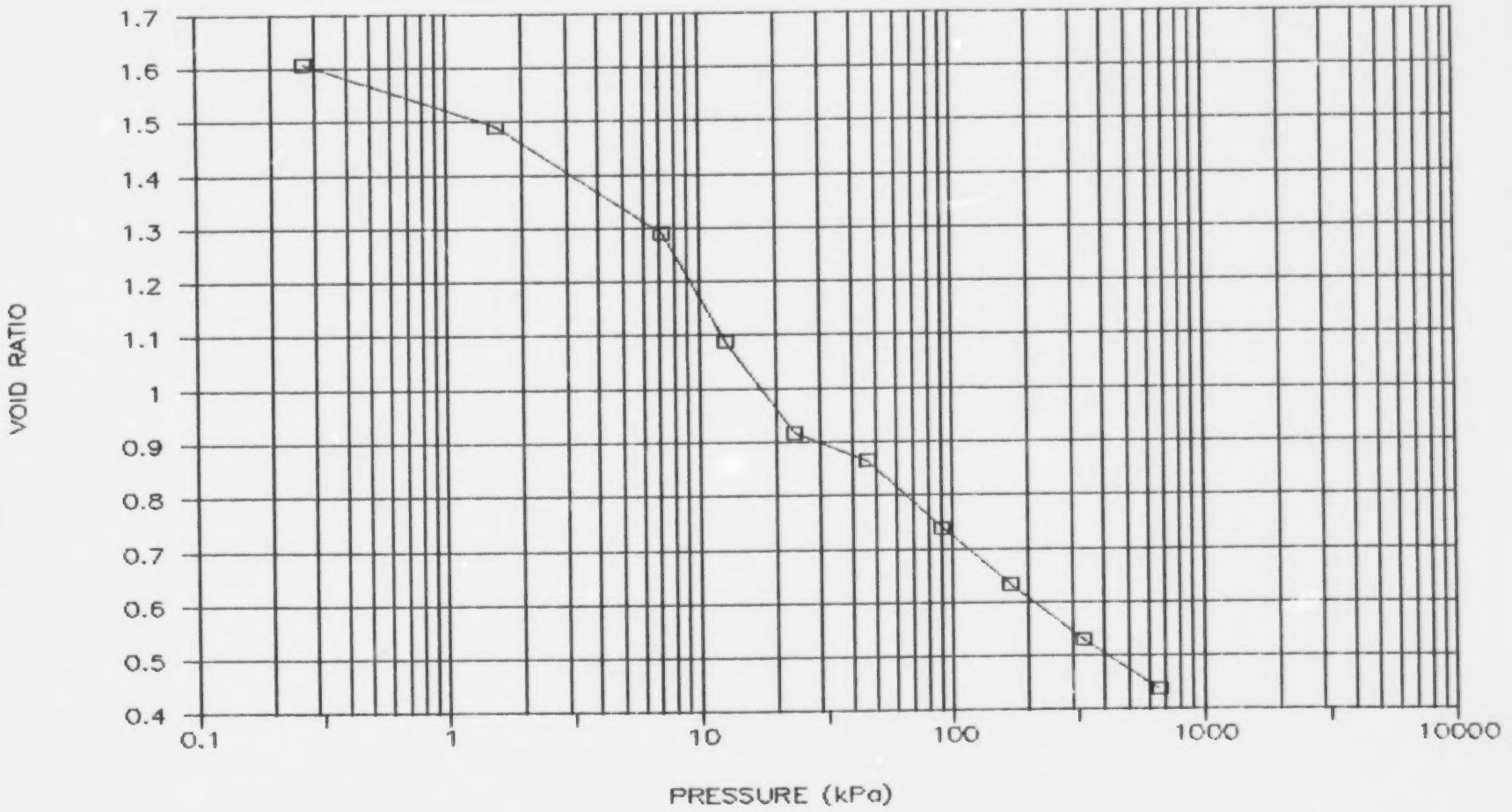
>>>T = 0.197 for 50% compression >>>> Cv = TH^2/t

Pressure (kPa)	Void Ratio	av	mv (m^2/kN)	H (cm)	t(50) (min)	Cv cm^2/sec	k (m/sec)
0.03	1.308	ERR	ERR	ERR	25.0	ERR	ERR
1.57	1.190	0.0326	0.0133	1.0296	42.0	8.29E-05	1.08E-07
7.17	1.075	0.0166	0.0068	0.9763	9.0	3.48E-04	2.31E-07
18.17	0.915	0.0087	0.0035	0.9131	4.0	6.84E-04	2.38E-07
40.65	0.783	0.0045	0.0018	0.8464	3.1	7.59E-04	1.35E-07
85.09	0.617	ERR	ERR	0.7781	4.0	4.97E-04	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR
ERR	ERR	ERR	ERR	ERR	#########	ERR	ERR

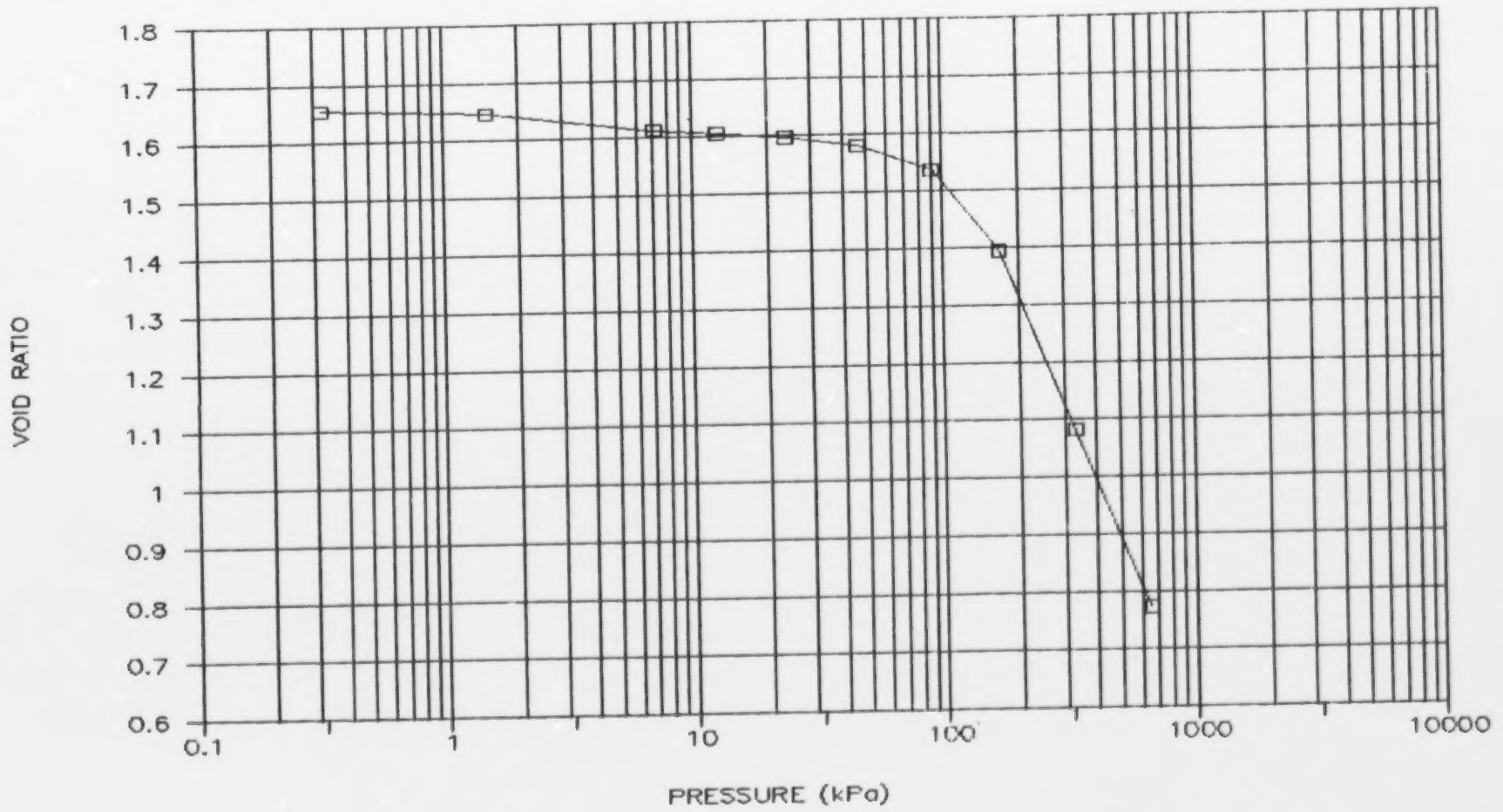
SAMPLE 1, SLIME (NATURAL)



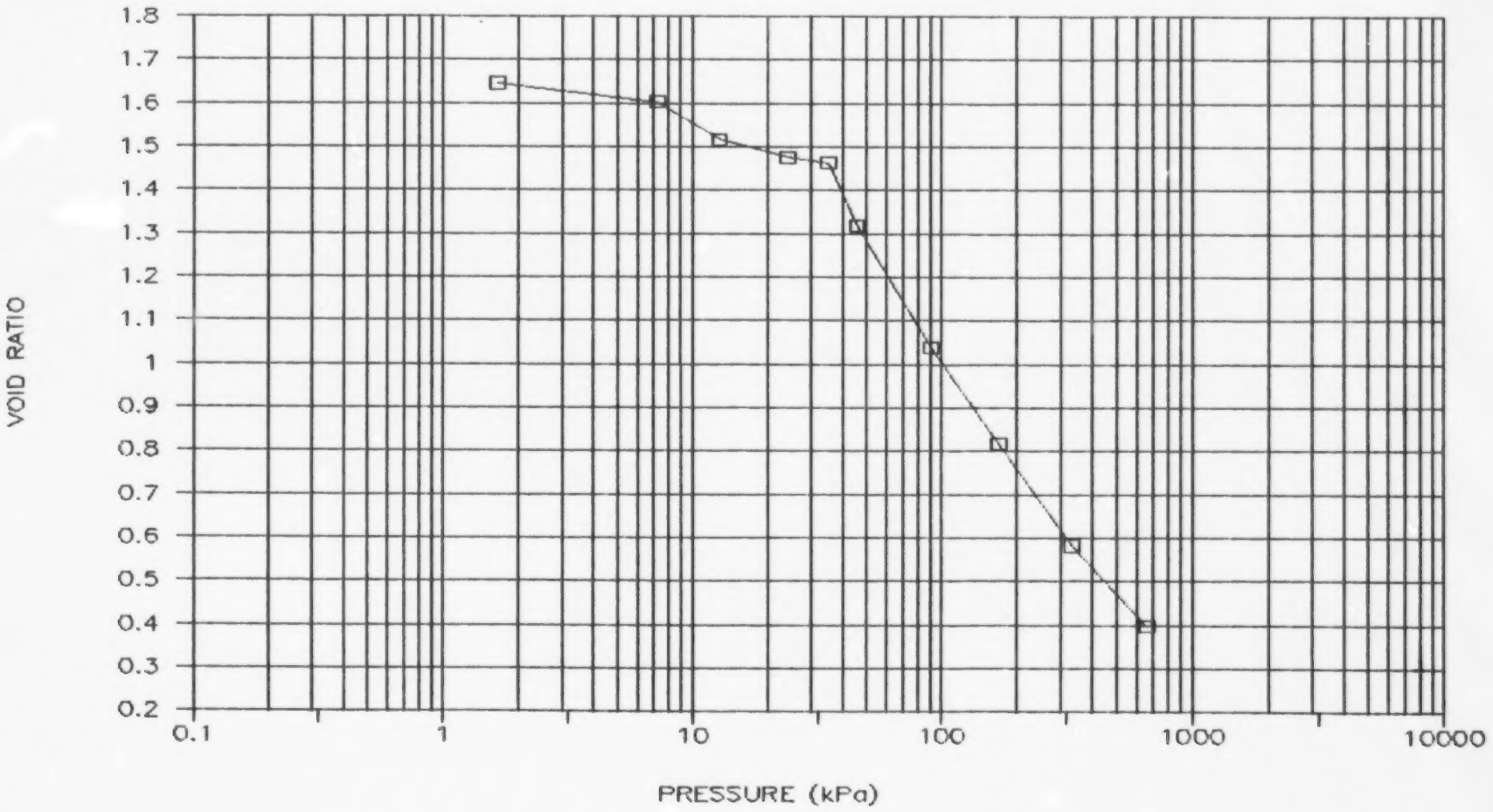
SAMPLE 2, SLIME (WASHED)



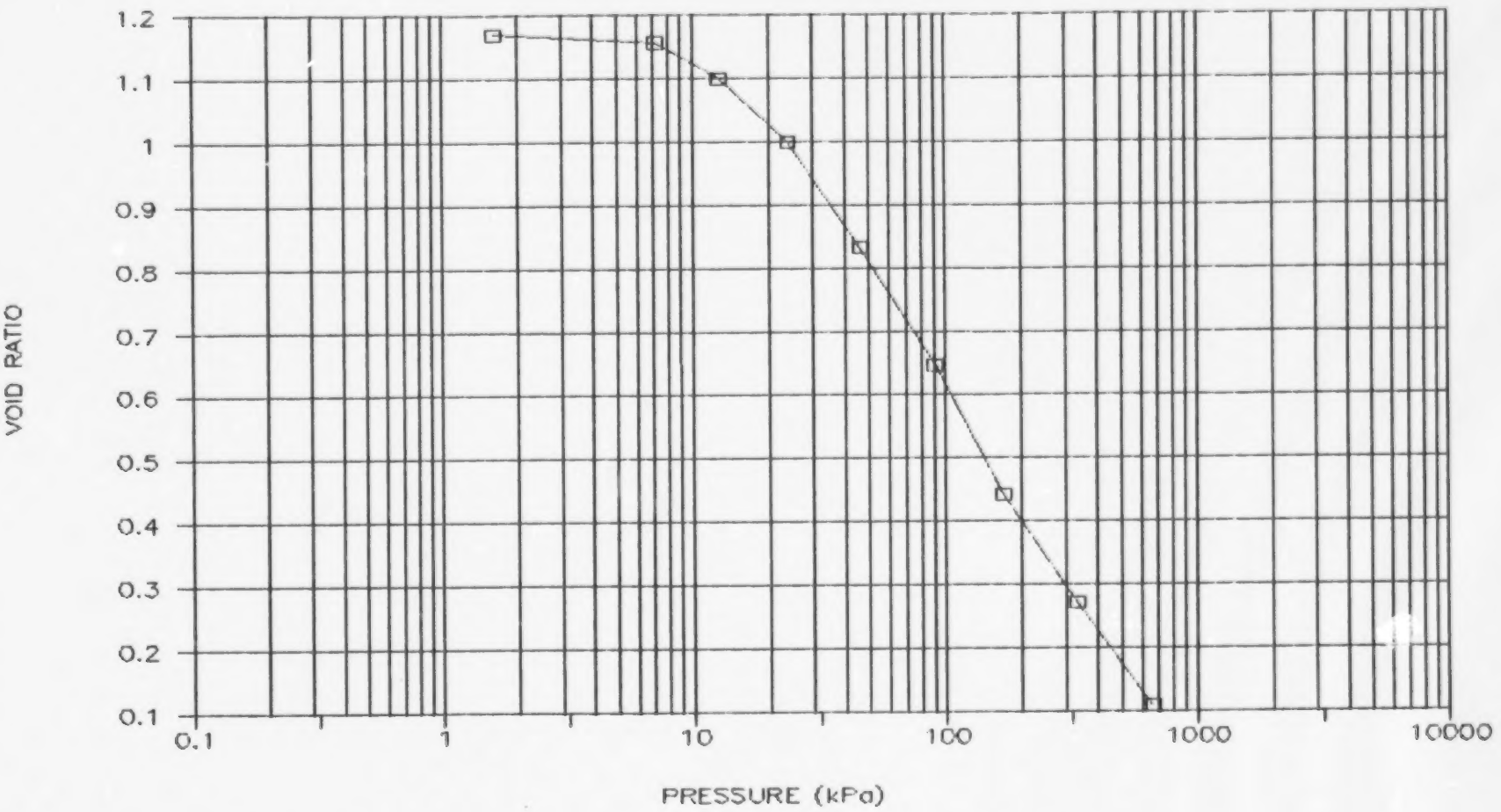
SAMPLE 4, TYPE 50 – 10%



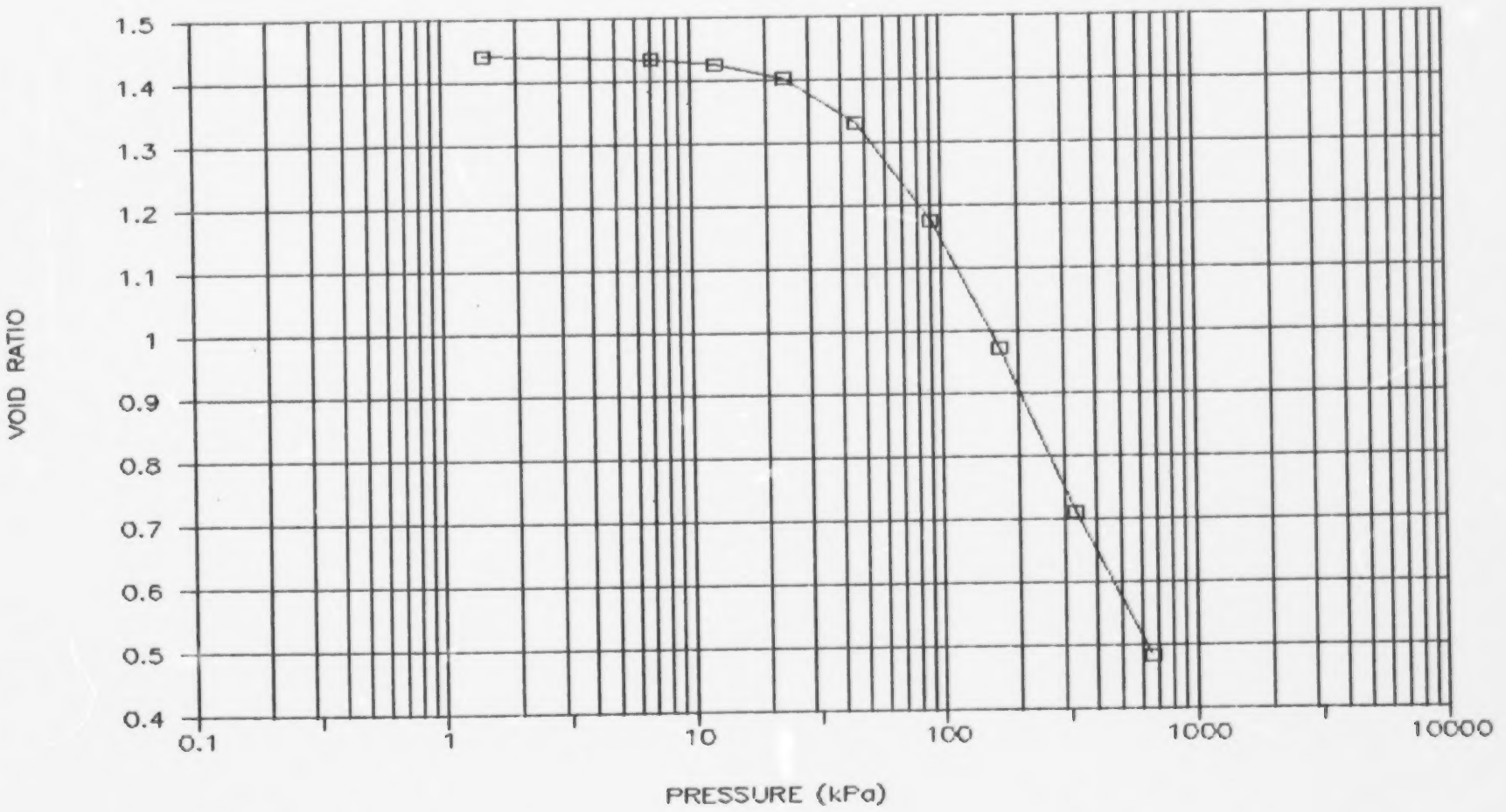
SAMPLE 5, TYPE 10 – 5%



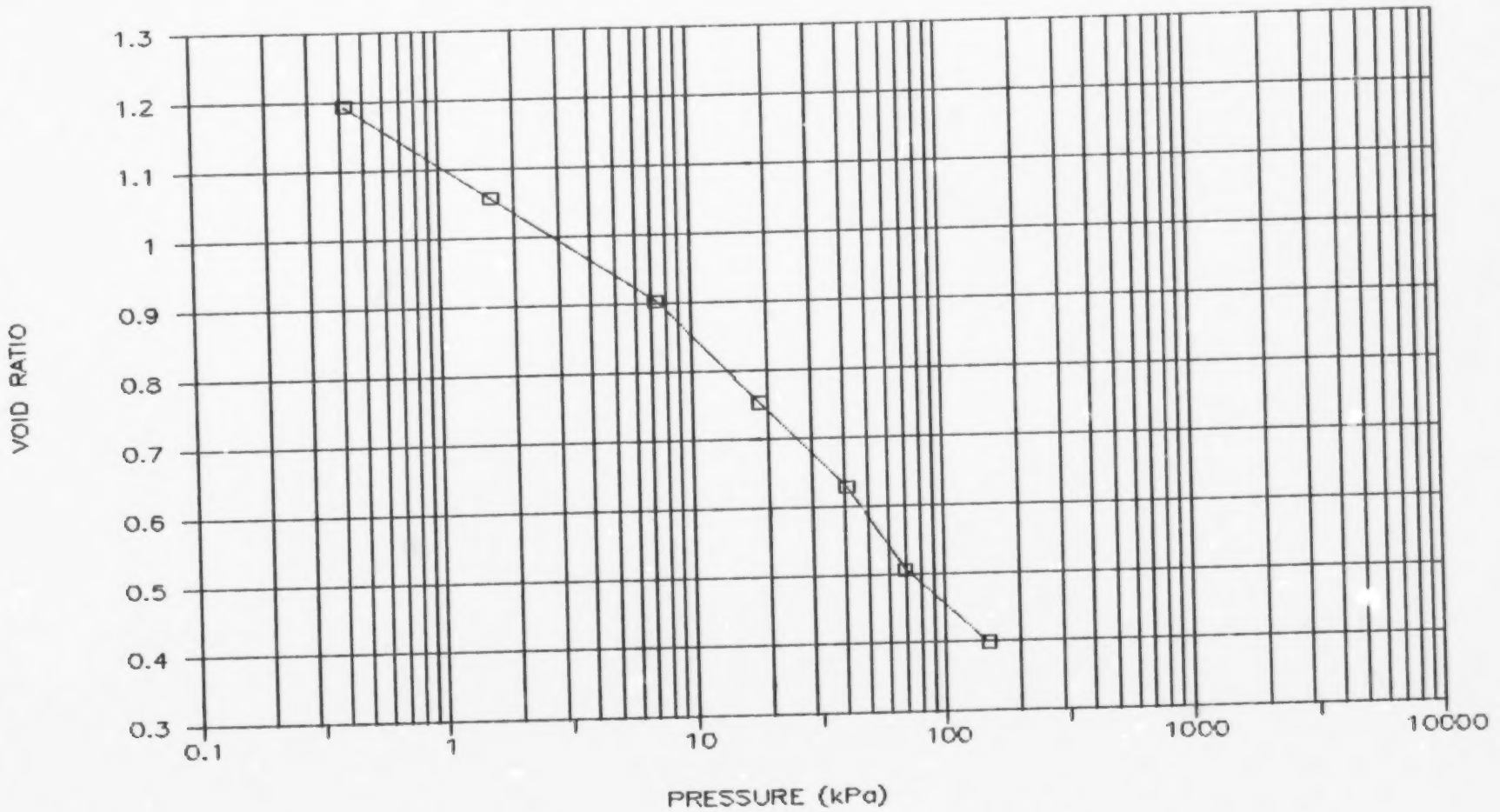
SAMPLE 6, TYPE 50 – 2.5%

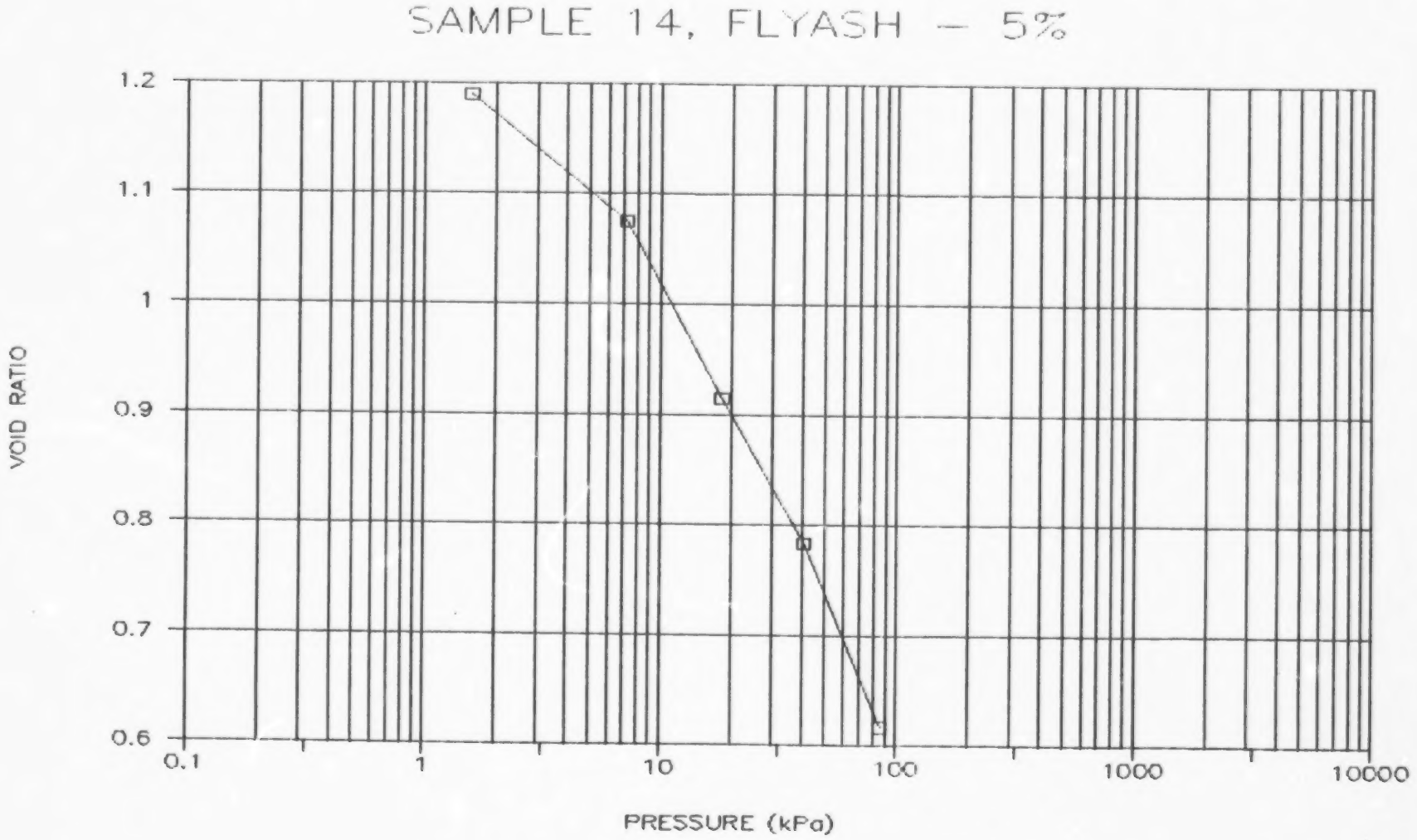


SAMPLE 8, TYPE 50 - 5%



SAMPLE 13, KALONITE – 5%




SAMPLE 14, FLYASH – 5%
VOID RATIO
1.2
1.1
1
0.9
0.8
0.7
0.6
0.1
1
10
100
1000
10000
PRESSURE (kPa)

APPENDIX C

UNCONFINED COMPRESSION TEST RESULTS

UNCONFINED COMPRESSED TEST
****

SAMPLE: 4
DESCRIPTION: TYPE 50 - 10%

DIAMETER: 4.75 cm. AREA = 17.72054 cm^2
HEIGHT: 10.18 cm.

LOAD	STRAIN	TOTAL STRAIN	UNIT STRAIN	1 - UNIT STRAIN	CORRECTED AREA	LOAD (kN)	VERTICAL STRESS (kPa)
0	0	0	0	1	0.001772	ERR	ERR
0.00015	0.025	0.025	0.002455	0.997544	0.001776	0.006105	3.436692
0.00027	0.05	0.05	0.004911	0.995088	0.001780	0.010989	6.170818
0.0004	0.075	0.075	0.007367	0.992632	0.001785	0.01628	9.119391
0.00053	0.1	0.1	0.009823	0.990176	0.001789	0.021571	12.05329
0.0008	0.15	0.15	0.014734	0.985265	0.001798	0.03256	18.10341
0.00122	0.2	0.2	0.019646	0.980353	0.001807	0.049654	27.47007
0.00168	0.25	0.25	0.024557	0.975442	0.001816	0.068376	37.63813
0.00244	0.3	0.3	0.029469	0.970530	0.001825	0.099308	54.38965
0.0027	0.35	0.35	0.034381	0.965618	0.001835	0.10989	59.88069
0.00318	0.4	0.4	0.039292	0.960707	0.001844	0.129426	70.16741
0.00342	0.45	0.45	0.044204	0.955795	0.001854	0.139194	75.07727
0.00352	0.49	0.49	0.048133	0.951866	0.001861	0.143264	76.95484

UNCONFINED COMPRESSED TEST
****

SAMPLE: A1
DESCRIPTION: TYPE 10 - 2.5%

DIAMETER: 4.75 cm. AREA = 17.72054 cm^2
HEIGHT: 10.9 cm.

LOAD	STRAIN	TOTAL STRAIN	UNIT STRAIN	1 - UNIT STRAIN	CORRECTED AREA	LOAD (kN)	VERTICAL STRESS (kPa)
0	0	0	0	1	0.001772	ERR	ERR
0.00003	0.05	0.05	0.004587	0.995412	0.001780	0.001221	0.685869
0.00006	0.1	0.1	0.009174	0.990825	0.001788	0.002442	1.365418
0.0001	0.15	0.15	0.013761	0.986238	0.001796	0.00407	2.265162
0.00011	0.2	0.2	0.018348	0.981651	0.001805	0.004477	2.480089
0.00012	0.25	0.25	0.022935	0.977064	0.001813	0.004884	2.692908
0.00015	0.3	0.3	0.027522	0.972477	0.001822	0.006105	3.350332
0.00017	0.35	0.35	0.032110	0.967889	0.001830	0.006919	3.779133
0.00019	0.4	0.4	0.036697	0.963302	0.001839	0.007733	4.203719
0.0002	0.45	0.45	0.041284	0.958715	0.001848	0.00814	4.403896
0.0002	0.5	0.5	0.045871	0.954128	0.001857	0.00814	4.382825
0.00021	0.55	0.55	0.050458	0.949541	0.001866	0.008547	4.579841
0.00022	0.6	0.6	0.055045	0.944954	0.001875	0.008954	4.774750
0.00022	0.65	0.65	0.059633	0.940366	0.001884	0.008954	4.751572
0.00022	0.75	0.75	0.068807	0.931192	0.001902	0.008954	4.705215
0.00022	0.8	0.8	0.073394	0.926605	0.001912	0.008954	4.682037
0.00022	0.85	0.85	0.077981	0.922018	0.001921	0.008954	4.658858
0.00022	0.9	0.9	0.082568	0.917431	0.001931	0.008954	4.635680
0.00022	0.95	0.95	0.087155	0.912844	0.001941	0.008954	4.612502

UNCONFINED COMPRESSED TEST
****

SAMPLE: A2
DESCRIPTION: TYPE 10 - 10%

DIAMETER: 4.75 cm. AREA = 17.72054 cm^2
HEIGHT: 11.28 cm.

LOAD	STRAIN	TOTAL STRAIN	UNIT STRAIN	1 - UNIT STRAIN	CORRECTED AREA	LOAD (kN)	VERTICAL STRESS (kPa)
0	0	0	0	1	0.001772	ERR	ERR
0.00008	0.025	0.025	0.002216	0.997783	0.001775	0.003256	1.833342
0.00026	0.05	0.05	0.004432	0.995567	0.001779	0.010582	5.945129
0.0005	0.075	0.075	0.006648	0.993351	0.001783	0.02035	11.40748
0.00067	0.1	0.1	0.008865	0.991134	0.001787	0.027269	15.25193
0.00098	0.15	0.15	0.013297	0.986702	0.001795	0.039886	22.20902
0.00138	0.2	0.2	0.017730	0.982269	0.001804	0.056166	31.13343
0.00172	0.25	0.25	0.022163	0.977836	0.001812	0.070004	38.62888
0.0021	0.3	0.3	0.026595	0.973404	0.001820	0.08547	46.94937
0.0022	0.35	0.35	0.031028	0.968971	0.001828	0.08954	48.96108
0.00278	0.4	0.4	0.035460	0.964539	0.001837	0.113146	61.58598
0.003	0.45	0.45	0.039893	0.960106	0.001845	0.1221	66.15427
0.0031	0.5	0.5	0.044326	0.955673	0.001854	0.12617	68.04381
0.0031	0.55	0.55	0.048758	0.951241	0.001862	0.12617	67.72821
0.0031	0.6	0.6	0.053191	0.946808	0.001871	0.12617	67.41261

UNCONFINED COMPRESSED TEST
****

SAMPLE: 5
DESCRIPTION: TYPE 10 - 5%

DIAMETER: 4.75 cm. AREA = 17.72054 cm^2
HEIGHT: 11.17 cm.

LOAD	STRAIN	TOTAL STRAIN	UNIT STRAIN	1 - UNIT STRAIN	CORRECTED AREA	LOAD (kN)	VERTICAL STRESS (kPa)
0	0	0	0	1	0.001772	ERR	ERR
0.00007	0.025	0.025	0.002238	0.997761	0.001776	0.002849	1.604139
0.00014	0.125	0.125	0.011190	0.988809	0.001792	0.005698	3.179493
0.0002	0.175	0.175	0.015666	0.984333	0.001800	0.00814	4.521571
0.0003	0.225	0.225	0.020143	0.979856	0.001808	0.01221	6.751513
0.00036	0.275	0.275	0.024619	0.975380	0.001816	0.014652	8.064804
0.00042	0.325	0.325	0.029095	0.970904	0.001825	0.017094	9.365759
0.0005	0.375	0.375	0.033572	0.966427	0.001833	0.02035	11.09830
0.0006	0.425	0.425	0.038048	0.961951	0.001842	0.02442	13.25628
0.00068	0.475	0.475	0.042524	0.957475	0.001850	0.027676	14.95387
0.00078	0.525	0.525	0.047000	0.952999	0.001859	0.031746	17.07278
0.00087	0.575	0.575	0.051477	0.948522	0.001868	0.035409	18.95327
0.00092	0.625	0.625	0.055953	0.944046	0.001877	0.037444	19.94796
0.00099	0.675	0.675	0.060429	0.939570	0.001886	0.040293	21.36396
0.00103	0.725	0.725	0.064905	0.935094	0.001895	0.041921	22.12125
0.00105	0.775	0.775	0.069382	0.930617	0.001904	0.042735	22.44284
0.00108	0.825	0.825	0.073858	0.926141	0.001913	0.043956	22.97303
0.00108	0.875	0.875	0.078334	0.921665	0.001922	0.043956	22.86200
0.00108	0.925	0.925	0.082811	0.917188	0.001932	0.043956	22.75096
0.00108	0.975	0.975	0.087287	0.912712	0.001941	0.043956	22.63993